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DEVELOPMENT OF A SYSTEMWIDE PREDATOR CONTROL PROGRAM: STEPWISE IMPLEMENTATION OF A PREDATION INDEX, PREDATOR CONTROL FISHERIES, AND EVALUATION PLAN IN THE COLUMBIA RIVER BASIN

SECTION II: EVALUATION

ANNUAL REPORT 1994

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In Cooperation With

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Pacific States Marine Fisheries Commission
Columbia River Inter-Tribal Fish Commission
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SECTION II. EVALUATION

Cooperators

Columbia Basin Fish and Wildlife Authority

S.P. Cramer and Associates, Inc.

Pacific States Marine Fisheries Commission

Oregon Department of Fish and Wildlife

REPORT F

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1994 Annual Report

CONTENTS

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A B S T R A C T

We are reporting progress on evaluation of the Northern Squawfish Management Program in 1994. Our objectives in 1994 were to (1) evaluate exploitation rate, size composition, and incidental catch of northern squawfish *(Ptychocheilus oregonensis)* captured in the various fisheries and estimate reductions in predation on juvenile salmonids since implementation of the management program, and (2) evaluate changes through 1994 in relative abundance, smolt consumption rate, size and age structure, growth, and fecundity of northern squawfish in lower Columbia and Snake River reservoirs and in the Columbia River downstream from Bonneville Dam.

Systemwide exploitation of northern squawfish in 1994 was 10.9% for sport-reward, 1.1% for dam-angling, and 1.1% for site-specific fisheries. Mean fork length was 344 mm in the sport-reward fishery, 401 mm in the dam-angling fishery, and 410 mm for gill nets in the site-specific fishery. Relative to the total number of fish caught, the dam-angling fishery reported the lowest percentage of incidental catch.

We estimate that potential predation on juvenile salmonids in 1995 may be reduced 32% from pre-program levels. Eventual reductions in potential predation varied depending on

estimates of sustained exploitation. However, it appeared feasible to reduce overall predation by at least 40%.

In general, relative abundance of northern squawfish in 1994 was similar to previous years in the Columbia River downstream from Bonneville Dam, but decreased in Columbia and Snake River reservoirs. Consumption indices decreased in Columbia River reservoirs and remained similar or increased in Snake River reservoirs and the Columbia River downstream from Bonneville Dam.

Proportional stock density (PSD) of northern squawfish collected from Bonneville Dam tailrace was lower in 1994 than in 1990. Estimates of PSD from 199 1- 1994 were generally below levels that would have been expected without implementation of the Northern Squawfish Management Program. Relatively strong recruitment in 1989 and 1990 will probably decrease PSD estimates in 1995 and 1996 as these relatively strong cohorts are recruited to “stock” size. Although length-age and fecundity-length relationships varied among years in some locations, we found no evidence of compensation by northern squawfish in any area.

INTRODUCTION

The goal of the Northern Squawfish Management Program is to reduce mainstem predation mortality on juvenile salmonids. From 1990 through 1992, we estimated the relative magnitude of northern squawfish (*Ptychocheilus oregonensis*) abundance, consumption, and predation in Columbia River impoundments (1990), Snake River impoundments (199 1), and the unimpounded lower Columbia River downstream from Bonneville Dam (1992). Those results established baseline levels of predation and described northern squawfish population characteristics throughout the lower basin before implementation of sustained predator control fisheries. In 1993, we again sampled Columbia River impoundments to evaluate changes from 1990. In 1994, we altered our sampling design to sample only areas where sufficient northern squawfish digestive tract samples could be collected to compare consumption indices among years: In this report, we describe our activities and findings in 1994 and, wherever possible, evaluate any changes from previous years.

Our objectives in 1994 were to (1) evaluate exploitation rate, size composition, and incidental catch of northern squawfish fisheries and estimate reductions in predation on juvenile salmonids since implementation of the management program, and (2) evaluate changes through 1994 in relative abundance, consumption, size and age structure, growth, and fecundity of northern squawfish in lower Columbia and Snake River reservoirs and in the Columbia River downstream from Bonneville Dam.

METHODS

Fishery Evaluation

Field Procedures

Three northern squawfish fisheries were conducted in 1994. The sport-reward fishery was implemented by the Washington Department of Fish and Wildlife (WDFW) from May 2 through September 25 throughout the lower Columbia and Snake rivers. The dam-angling fishery was implemented by the Columbia River Inter-Tribal Fish Commission (CRITFC), Confederated Tribes of the Warm Springs Reservation of Oregon, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes and Bands of the Yakama Indian Nation (YIN), and the Nez Perce Tribe (NPT) from May 9 to September 6 at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams. A site-specific fishery using both gill nets and Merwin traps was implemented by CRITFC, YIN, and NPT from April 8 through June 9 in Bonneville, The Dalles, John Day, McNary, Lower Monumental, Little Goose, and Lower Granite reservoirs.

We estimated exploitation rates of northern squawfish for each fishery based on recovery of fish tagged primarily before implementation of 1994 fisheries. We used electrotishing boats and bottom gill nets to collect northern squawfish from March 1 to May 3 1. Sampling effort was randomly allocated in all river kilometers (RKm) from RKm 71 through Priest Rapids Dam tailrace (RKm 639) on the lower Columbia River, and on the Snake River from RKm 0 through Lower Granite Reservoir (excluding Ice Harbor Reservoir). Fish greater than.225 mm fork length were tagged with a serially numbered "spaghetti" tag and given a secondary mark (right pelvic fin clip). Tags were recovered from each fishery from April 8 through September 25.

We measured fork lengths of northern squawfish from a subsample of fish harvested in sport-reward and dam-angling fisheries. Fork lengths from subsamples of fish harvested by the site-specific fishery were provided by CRITFC. Catch composition was provided for the respective fisheries by WDFW (sport reward) and CRITFC (dam angling and site-specific fishery).

Data Analysis

We used mark-and-recapture data to compare exploitation rates of northern squawfish among fisheries and reservoirs (Appendix A). Exploitation rates were calculated for one-week periods and summed to yield total exploitation rates for each fishery (Beamesderfer et al. 1987). We adjusted exploitation rates for tag loss (4.4%) during the season and calculated 90% confidence intervals for reservoir-specific and systemwide estimates.

We compared mean fork lengths of northern squawfish, length frequencies, and incidental catches in 1994 among fisheries. We also compared mean fork lengths of fish harvested by sport-reward and dam-angling fisheries among years (1990-l 994).

We used the Loss Estimate Spreadsheet Model (Zimmerman et al. 1995) to estimate reductions in predation relative to predation prior to implementation of the management program. The model incorporates age-specific exploitation rates on northern squawfish and resulting changes in age structure to estimate changes in predation. We used a lo-year "average" age structure (based on catch curves) for a pre-exploitation base, and assumed constant recruitment. Age-specific consumption of juvenile salmonids by northern squawfish is incorporated, however, potential changes in consumption, growth, and fecundity due to removals were not considered likely. The model therefore estimates changes in potential predation related directly to removals. This in effect allows us to estimate what the effects of removals would be if we were able to hold all variables except exploitation constant.

We estimated both the potential predation reduction in 1995 based on observed exploitation rates in 1994, and the eventual maximum potential- predation reduction assuming (1) continuing exploitation at 1994 levels, and (2) continuing exploitation at mean 1991-94 levels. In addition to reductions in overall predation, we estimated reductions in predation on juvenile salmonids originating in the Snake River upstream from Lower Granite Dam. We calculated 90% confidence intervals for all predation reduction estimates.

Biological Evaluation

Field Procedures

To evaluate changes in relative abundance and consumption, we used boat electrofishing to collect northern squawfish in the following areas: upper Lower Granite Reservoir (RKm 221-229), Lower Granite Dam tailrace, Little Goose Dam tailrace, John Day Reservoir, The Dalles Reservoir (excluding midreservoir), Bonneville Reservoir, Bonneville Dam tailrace, and three sections in the Columbia River downstream from Bonneville Dam tailrace (RKm 117-121, RKm 171-177, and RKm 190-196). The three sections sampled downstream of Bonneville Dam tailrace were selected to represent sections sampled in previous years (RKm 7 1- 12 1, RKm 122-177, and RKm 178-224). Sampling schedules, methods, and gear specifications were as described in previous reports (Vigg et al. 1990; Ward et al. 199 1; Parker et al. 1992; Zimmerman et al. 1995). We collected and preserved guts of all northern squawfish ≥250 mm fork length per methods of Petersen et al. (1991).

To evaluate changes in population structure, growth, and reproduction, we collected biological data from all northern squawfish collected by electrofishing, and from a subsample of northern squawfish caught in the sport-reward and dam-angling fisheries. We measured fork length (mm) and total body weight (g), determined sex (male, female, undetermined) and maturity (undeveloped or immature, developing, ripe, or spent), and collected gonad (ripe females only) and scale samples.

Laboratory Procedures

We examined gut contents of northern squawfish collected by electrofishing to measure consumption of juvenile salmonids by northern squawfish. Details of laboratory methods are given in Petersen et al. (1991). We used gravimetric quantification (Bagenal 1968) to estimate northern squawfish fecundity and used scale samples collected primarily by electrofishing for age determinations. Details of fecundity and aging procedures are given in Parker et al. (1995).

Data Analysis

We used catch per unit effort of standardized electrofishing runs as an index of northern squawfish density because it best reflected differences in northern squawfish abundance among areas and reservoirs (Ward et al. 1995). We compared density indices from 1990 through 1994 for all sampling areas. We calculated indices of northern squawfish abundance as the product of the northern squawfish density index'and reservoir or area-specific surface area (Ward et al. 1995), and compared indices among years for all sampling areas.

The following formula was developed as a consumption index (CI) by the NBS (Petersen et al. 1991):

$$CI = 0.0209 \cdot T^{1.60} \cdot MW^{0.27} \cdot (S \cdot GW^{-0.61})$$

where

T = water temperature (°C),
MW = mean predator weight (g),
S = mean number of salmonids per predator, and
GW = mean gut weight (g) per predator.

The consumption index is not a rigorous estimate of the number of juvenile salmonids eaten per day by an average northern squawfish. However, it is linearly related to the consumption rate of northern squawfish (Petersen et al. 1991). Spring (May - June) and summer (July-September) consumption indices were compared from 1990 through 1994 for all sampling areas except Snake River reservoirs, which were sampled only in the spring. To compare timing of consumption index sampling with concentrations of juvenile salmonids present in each area, we plotted the daily juvenile salmonid passage index for each lower Columbia and Snake River dam. We used the product of abundance and consumption indices to calculate predation indices for spring and summer periods in each year. We limited our comparison of predation indices to reservoir sections where data had been collected each year.

Because fishery exploitation rates increase with increasing size of northern squawfish (Zimmerman et al. 1995), sustained fisheries should decrease the abundance of large fish relative to the abundance of smaller fish. We used proportional stock density [PSD = 100 (number of fish at least quality length)/(number of fish at least stock length)] to compare size structure of northern squawfish populations among years from 1990 through 1994 in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir (Anderson 1980). Stock and quality sizes for northern squawfish have been defined as 250 mm and 380 mm fork length (Beamesderfer and Rieman 1988; Parker et al. 1995).

Comparisons of PSDs among years may be biased by (1) fluctuating year-class strengths that influence the number of stock-size fish (Mesa et al. 1990), and (2) size-selectivity of sampling gear (Beamesderfer and Rieman 1988). To help reduce bias, we used information on relative year-class strengths and natural mortality rates of northern squawfish to estimate PSDs that would be expected with and without program implementation (Appendix B). We also determined size selectivity of our sampling gear to adjust observed PSD estimates (Appendix B). We then compared observed and expected PSDs.

To evaluate changes in growth rate after implementation of the management program, we used length-at-age data from female northern squawfish to determine growth relationships for three areas: downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir. We determined regression parameters (slope and y-intercept) for fork length on age and compared relationships among years (1990-1994) for each area using joint 90% family confidence regions for estimates of parameter pairs (Neter et al. 1985). Parameter pairs were considered significantly different if point estimates (center-point of ellipse) were not within the confidence region for another year.

To evaluate changes in fecundity, we calculated mean fecundity (number of developed eggs per female) and mean relative fecundity (number of developed eggs per gram of body weight) from 199 1 through 1994 (fecundity data were not available for 1990) 'for three areas: downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir. We also determined regression parameters (slope and y-intercept) for the regression of fecundity on fork length and compared relationships among years (199 1- 1994) for each area using joint 90% family confidence regions for estimates of parameter pairs (Neter et al. 1985).

RESULTS

Fishery Evaluation

We tagged and released 2,476 northern squawfish throughout the lower Columbia and Snake rivers (Appendix A). A total of 282 marked northern squawfish were recaptured in the three fisheries: 236 by sport-reward anglers, 24 by dam anglers, and 22 by the site-specific gill-net fishery. Additionally, 12 tags were recovered during ODFW electrofishing and gill-net sampling, two were recovered by other ODFW crews, and eight were recovered by sport anglers not participating in the sport-reward fishery.

The sport-reward fishery had the highest exploitation rate of northern squawfish among fisheries in nearly all areas in 1994 (Figure 1; Appendix Table A-l). Sport-reward exploitation was higher in 1994 than 1993 in all locations except McNary, Lower Monumental, and Lower Granite reservoirs (Appendix Table A-2). Dam-angling exploitation was lower in 1994 than 1993 in two of three areas where tags were recovered both years (Appendix Table A-3). Exploitation estimates were zero for dam angling in 1994 in The Dalles Reservoir although over 3,000 fish were caught because no tagged northern squawfish were recovered (Columbia River Inter-Tribal Fish Commission, unpublished data).- Exploitation estimates were also zero for dam angling in McNary, Lower Monumental, and Lower Granite reservoirs, but catch totaled only 136 fish in these reservoirs. The site-specific gill-net fishery had a relatively high exploitation rate in Bonneville Reservoir, where most of the effort (82%) was concentrated (K. Collis, Columbia River Inter-Tribal Fish Commission, personal communication).

Systemwide exploitation rate (all fisheries combined) of northern squawfish $\geq$250 mm during 1994 was 13.1% (Figure 1; Appendix Table A-l), which was higher than previous years (Table 1). Reservoir-specific exploitation rates were higher in 1994 than 1993 in Bonneville, The Dalles, and Little Goose reservoirs, and the Columbia River downstream from Bonneville Dam. Reservoir-specific exploitation rates are conservative because they exclude fish that were recaptured in reservoirs other than where marked, whereas systemwide exploitation rates include all recaptured northern squawfish. Confidence intervals for exploitation estimates were typically widest for reservoirs in which relatively few fish were tagged. However, bounds for systemwide exploitation estimates were relatively narrow. We did not estimate exploitation in Ice Harbor Reservoir from 1992 through 1994 because no northern squawfish were tagged.

As in previous years, the sport-reward and dam-angling fisheries harvested a disproportional number of large northern squawfish (Figure 2). Mean fork length was 344 mm in the sport-reward fishery and 401 mm in the dam-angling fishery. Mean fork length for northern squawfish captured in the site-specific fishery was 410 mm for gill nets and 233 mm for Merwin traps.

Mean size of northern squawfish harvested in each reservoir by dam angling in 1994 was generally within the range for previous years (Table 2). However, mean fork length increased in John Day Reservoir and decreased below Bonneville Dam. The size of fish harvested in 1994 by sport-reward anglers above John Day Dam varied considerably from previous years (Table 2). However, the significance of these changes is uncertain because of small sample sizes in John Day, Ice Harbor, Lower Monumental, and Little Goose reservoirs.

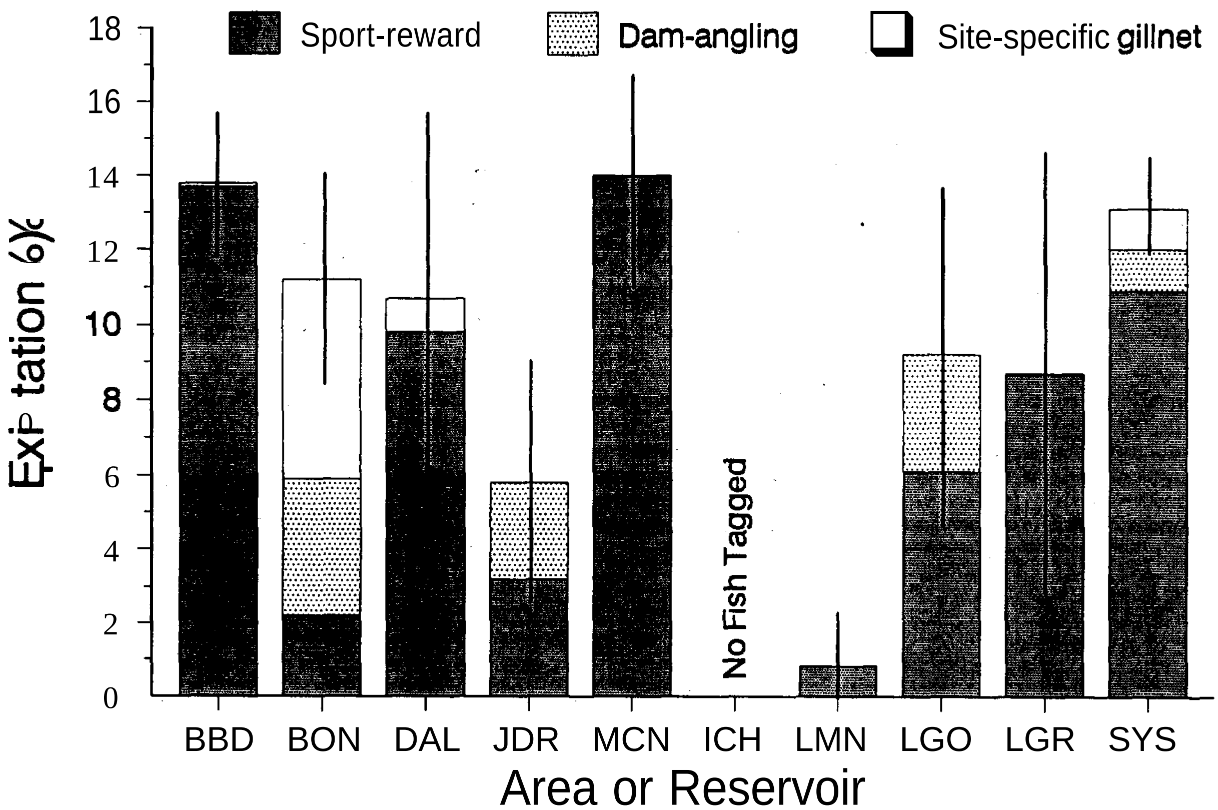

Figure 1. Exploitation rates (%) of northern squawfish ≥250 mm among areas and fisheries in 1994. BBD = Below Bonneville Dam, BON = Bonneville Reservoir, DAL = The Dalles Reservoir, JDR = John Day Reservoir, MCN = McNary Reservoir, ICH = Ice Harbor Reservoir, LMN = Lower Monumental Reservoir, LGO = Little Goose Reservoir, LGR = Lower Granite Reservoir, and SYS = Systemwide. Vertical bars represent 90% confidence intervals around total (all fisheries combined) exploitation estimates. The site-specific Merwin trap fishery is excluded because only six northern squawfish ≥250 mm fork length were caught.

Table 1. Total exploitation rates (all fisheries combined) of northern squawfish ≥ 250 mm, 1991-94

Area or reservoir	1991	1992	1993	1994
Downstream from Bonneville Dam	8.1	11.8	7.1	13.8
Bonneville	15.2	6.8	4.6	11.2
The Dalles	10.5	7.2	7.0	10.7
John Day	13.3	14.3	10.5	5.8
McNary	5.2	5.6	16.5	14.0
Ice Harbor	17.5	--	--	--
Lower Monumental	27.0	7.7	3.1	0.8
Little Goose	18.4	18.1	6.6	9.2
Lower Granite	16.8	14.6	12.6	8.1
Systemwide	11.3	12.2	8.5	13.1

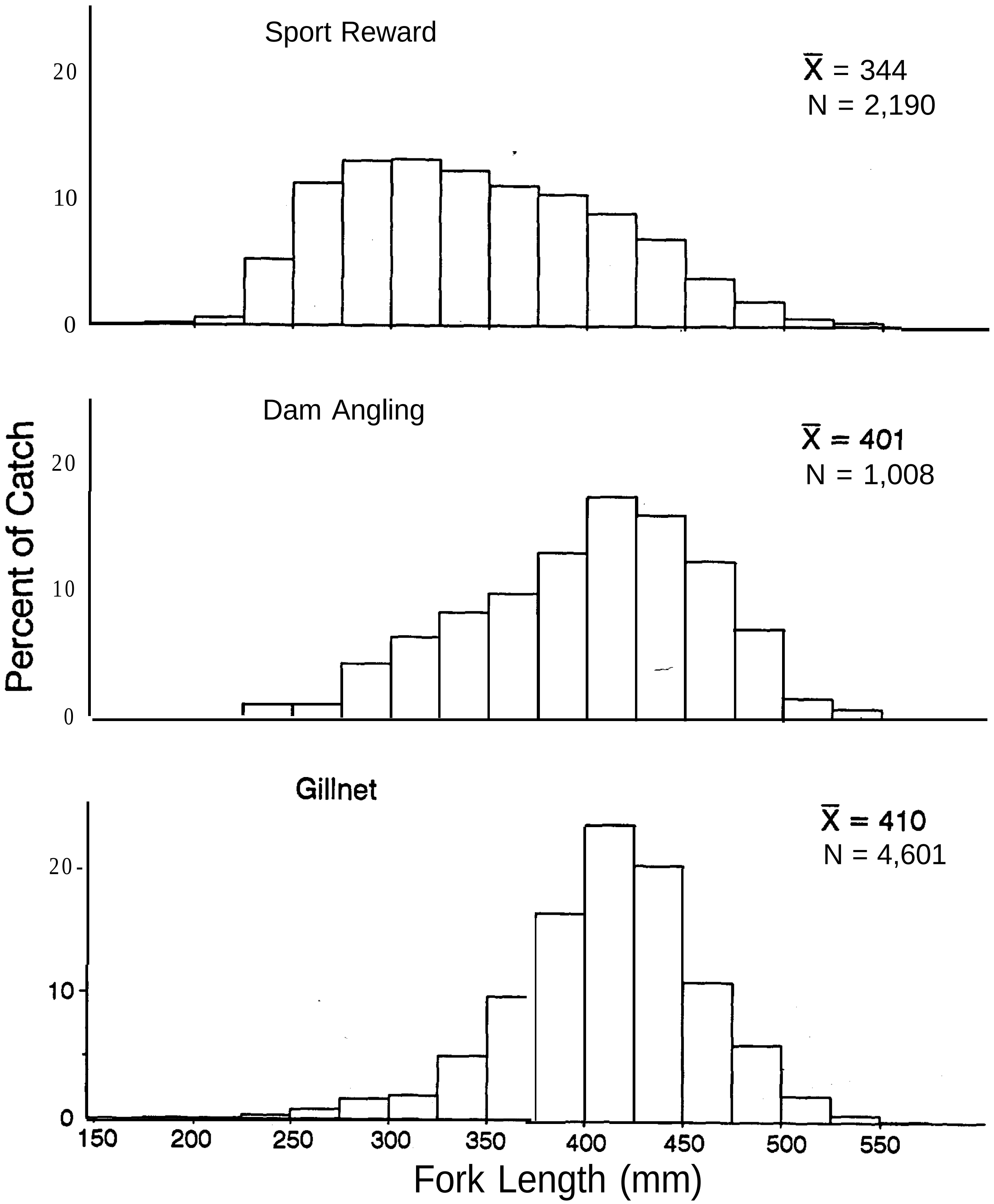

Figure 2. Size composition and mean fork length of northern **squawfish** in subsamples of fish harvested systemwide in sport-reward, dam-angling, and site-specific gill-net fisheries in 1994. N = subsample size.

Table 2. Mean fork length (mm) of northern squawfish harvested from 1990 through 1994 in sport-reward and dam-angling fisheries downstream from Bonneville Dam, and in each lower Columbia and Snake River reservoir.

Fishery: location	Mean fork length (mm)				
	1990	1991	1992	1993	1994
Dam Angling:					
Bonneville Dam Tailrace	414	417	388	390	376
Bonneville Reservoir	407	417	416	415	413
The Dalles Reservoir	421	404	380	420	390
John Day Reservoir	416	414	417	416	437
McNary Reservoir	393	393	375	408	--
Ice Harbor Reservoir	--	375	369	414	--
Lower Monumental Reservoir	--	325	309	341	--
Little Goose Reservoir	--	380	346	373	370
Lower Granite Reservoir	--	--	--	377	--
Sport Reward:					
Downstream from Bonneville Dam	--	332	337	316	337
Bonneville Reservoir	--	343	347	312	323
The Dalles Reservoir	--	344	369	369	358
John Day Reservoir	377	370	367	370	329
McNary Reservoir	--	354	356	358	366
Ice Harbor Reservoir	--	357	360	317	407
Lower Monumental Reservoir	--	338	330	307	428
Little Goose Reservoir	--	312	347	344	376
Lower Granite Reservoir	--	343	345	362	348

Incidental catch varied among fisheries (Table 3). Relative to the total number of fish caught, the dam-angling fishery reported the lowest incidental catch (2.3%). Sport-reward incidental catch was also relatively low (9.4%) and consisted mostly of smallmouth bass (*Micropterus dolomieui*). Incidental catch was highest in the site-specific fishery (37.9% for gill nets and 85.6% for Merwin traps) with suckers (*Catostomus* spp.) comprising the largest proportion (26%) of incidentally caught species. The proportion of predator-sized northern squawfish (≥250 mm fork length) relative to the total number of squawfish harvested was very low (11.1%) for Merwin traps. In contrast, most northern squawfish caught in sport-reward (94.4%), dam-angling (100.0%), and site-specific gill-net (99.0%) fisheries were ≥250 mm in fork length.

Results from the Loss Estimate Spreadsheet Model indicate that potential predation on juvenile salmonids in 1995 may be reduced 32% from pre-program levels (Table 4). Predation on Snake River stocks will be similar to predation on other stocks. Eventual reductions in potential predation vary depending on estimates of sustained exploitation. However, based on observed exploitation rates, it appears feasible to reduce potential predation by approximately 40%.

Table 3. Number of northern squawfish and incidentally caught fish by species or family in each fishery in 1994. Sport-reward fishery incidental catch represents only those anglers returning to registration stations (S. Smith, Washington Department of Fish and Wildlife, personal communication).

Species or family	Sport reward	Dam angling	Site-specific Gill net	Site-specific Merwin trap
Northern squawfish				
≥ 250 mm fork length	129,434	16,097	9,018	6
< 250 mm fork length	7,707	0	87	48
Channel catfish	367	43	376	0
Smallmouth bass	6,371	170	51	14
Walleye[a]	950	40	98	0
White sturgeon[a]	1,568	74	401	0
American shad[a] (adult)	437	11	36	0
Salmonidae[a]:				
Chinook (adult)	15	0	81	0
Chinook (juvenile)		0	0	0
Sockeye (adult)		0	1	0
Coho (adult)	2	0	0	0
Steelhead (adult)	77	0	48	3
Steelhead (juvenile)		0	0	0
Unknown (adult)	62	12	0	0
Unknown (juvenile)	201	0	10	147
Mountain Whitefish[a]	56	0	46	0
Other	239	0	4	0
Other cyprinidae[b]	2,060	--	437	146
Catostomidae[b]	912	--	3,832	7
Other	886	24	135	3
Total (all species)	151,344	16,471	14,661	374
Percent incidental catch	9.4	2.3	37.9	85.6

[a] Walleye = ***Stizostedion vitreum vitreum,*** white sturgeon = ***Acipenser transmontanus, american*** shad = ***Alosa sapidissima,*** salmonids = ***Oncorhynchus*** spp., mountain whitefish = ***Prosopium williamsoni.***

[b] All "non-game" fish caught by dam-angling are classified as "other."

Table 4. Comparison of predicted reductions in potential predation of juvenile salmonids relative to predation prior to implementation of the Northern Squawfish Management Program. Snake River stocks are juvenile salmonids originating upstream from Lower Granite Dam. Numbers in parenthesis represent 90% confidence intervals for estimates of potential predation reduction. Estimates from "Loss Estimate Spreadsheet" (Zimmerman et al. 1995)

	All stocks		Snake River stocks	
	Reduction in predation	Year reached	Reduction in predation	Year reached
Potential predation reduction in 1995	**32% (23-38%)**	**--**	**32% (23-38%)**	**--**
Maximum potential predation reduction with 1994 exploitation levels continued	**40% (32-46%)**	1999	**40% (3 2-46%)**	1999
Maximum potential predation reduction with mean 199 1 - 1994 exploitation levels continued	37% (28-43%)	2001	**38% (29-44%)**	**2002**

Biological Evaluation

From 1990 through 1994, density and relative abundance of northern squawfish ≥250 mm changed little in the Columbia River downstream from Bonneville Dam, but decreased in most Columbia and Snake River reservoirs (Appendix Tables C-l and C-2; Figure 3). Among Columbia River reservoirs, the percent change in relative abundance from 1990 to 1994 was highest in The Dalles Reservoir (-7 1%) and lowest in John Day Reservoir (-54%). The percent decrease in relative abundance from 1991 to 1994 was greatest in sections of Snake River reservoirs; -84% for Lower Monumental Reservoir tailrace, -75% for Little Goose Reservoir tailrace, and -71% for upper Lower Granite Reservoir.

Consumption indices for sections of Columbia River reservoirs sampled in 1994 were generally lower than those observed in previous years (Appendix Tables C-3 and C-4). This was especially true in tailrace boat restricted zones (BRZs) of The Dalles and John Day reservoirs in summer. In the Columbia River downstream from Bonneville Dam and in sections of Snake River reservoirs, consumption indices were similar to or higher than those observed in past years. High spring flows precluded us from sampling in the tailrace BRZs of Bonneville and John Day reservoirs in 1993, and Bonneville, The Dalles, and Lower Monumental Reservoir BRZs in 1994. As a result, we were unable to calculate consumption indices for those areas. Sampling times typically coincided with peaks in downstream passage of juvenile salmonids, except at Bonneville Dam (Appendix D).

Decreased abundance or consumption indices for most areas in 1994 resulted in predation index values that were lower than previously observed, particularly in summer (Appendix Tables C-5 and C-6; Figure 4). The percent change from 1990 to 1994 in predation indices during summer was -47% at Bonneville Dam tailrace, -94% at The Dalles Reservoir (excluding midreservoir), and -89% at John Day Reservoir. The percent change from 1991 to 1994 at Snake River reservoirs in the spring was -73% at Lower Monumental Reservoir tailrace, -61% at Little Goose Reservoir tailrace, and -42% at upper Lower Granite reservoir. Predation index values for the three sections downstream from Bonneville Dam tailrace remained similar between 1992 and 1994 for the spring, but varied considerably in the summer (+228% at RKm 71-121;-72% at RKm 178-224).

Proportional stock density (PSD) expected without implementation of the Northern Squawfish Management Program increased from 1991 to 1994 in Bonneville Dam tailrace and John Day Reservoir (Figure 5). This increase was attributable to a relatively strong 1985 year class being recruited from stock- to quality-size from 1992 through 1994. Observed PSD decreased in Bonneville Dam tailrace and remained similar in Bonneville and John Day reservoirs from 1990 to 1994 (Figure 5). Observed PSDs were usually lower each year than would have been expected without the implementation of the Northern Squawfish Management Program. However, annual changes in observed PSDs did not always parallel expected values. Observed PSD estimates varied widely in Bonneville Reservoir between 1991 and 1994, but remained relatively similar each year in John Day Reservoir.

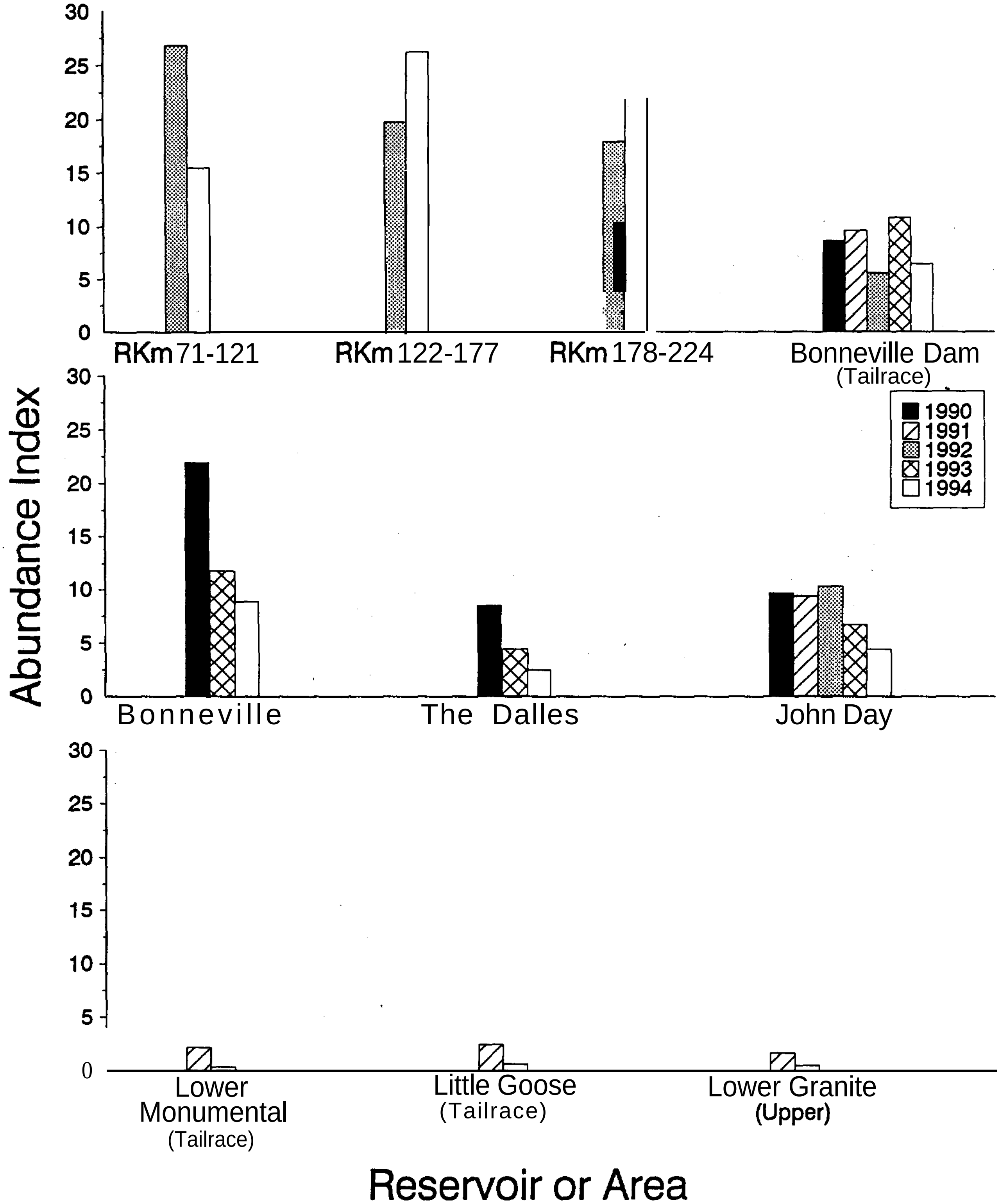

Figure 3. Index of northern squawfish abundance from 1990 through 1994 for sampling locations within the lower Columbia and Snake rivers.

Comparisons of confidence regions for joint estimates of parameters in length-age equations for female northern squawfish indicated that growth relationships in 1994 were not significantly different from most other years (Figure 6). In John Day Reservoir, parameter estimates did not differ significantly among any years from 1990 through 1994.

Comparisons of confidence regions for joint estimates of parameters infecundity-length equations for 1991 through 1994 indicated that relationships varied slightly among years in some areas (Figure 7). In Bonneville Reservoir and the Columbia River downstream from Bonneville Dam, differences in parameter estimates were significant between 1991 and some other years. However, in John Day Reservoir, parameter estimates did not differ significantly among any years. Estimates of mean fecundity and mean relative fecundity changed little or decreased between 1990 and 1994 in all three areas (Table 5).

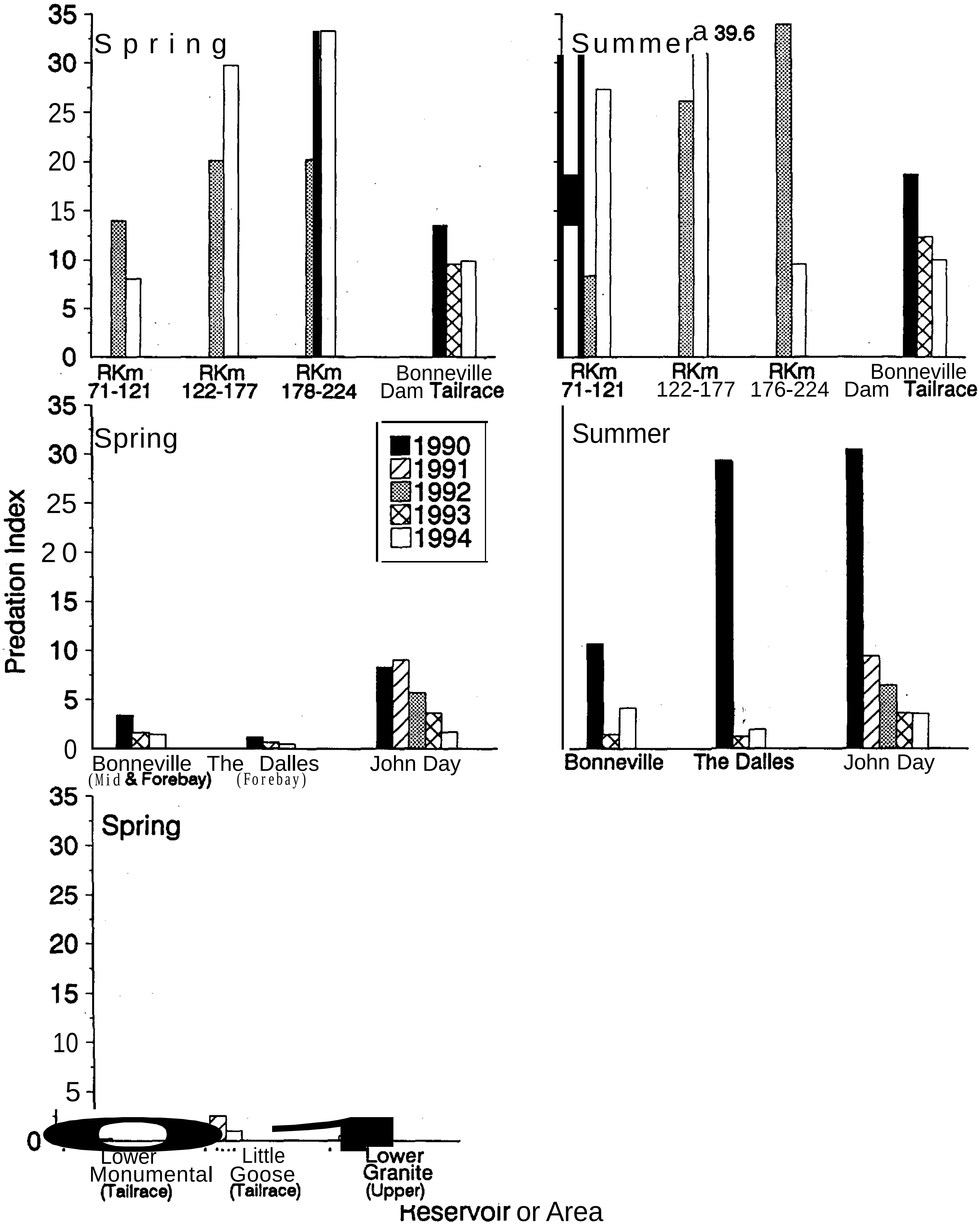

Figure 4. Index of northern squawfish predation for spring and summer from 1990 through 1994 for sampling locations within the lower Columbia and Snake rivers, Predation indices for The Dalles Reservoir in summer excludes the midreservoir section.

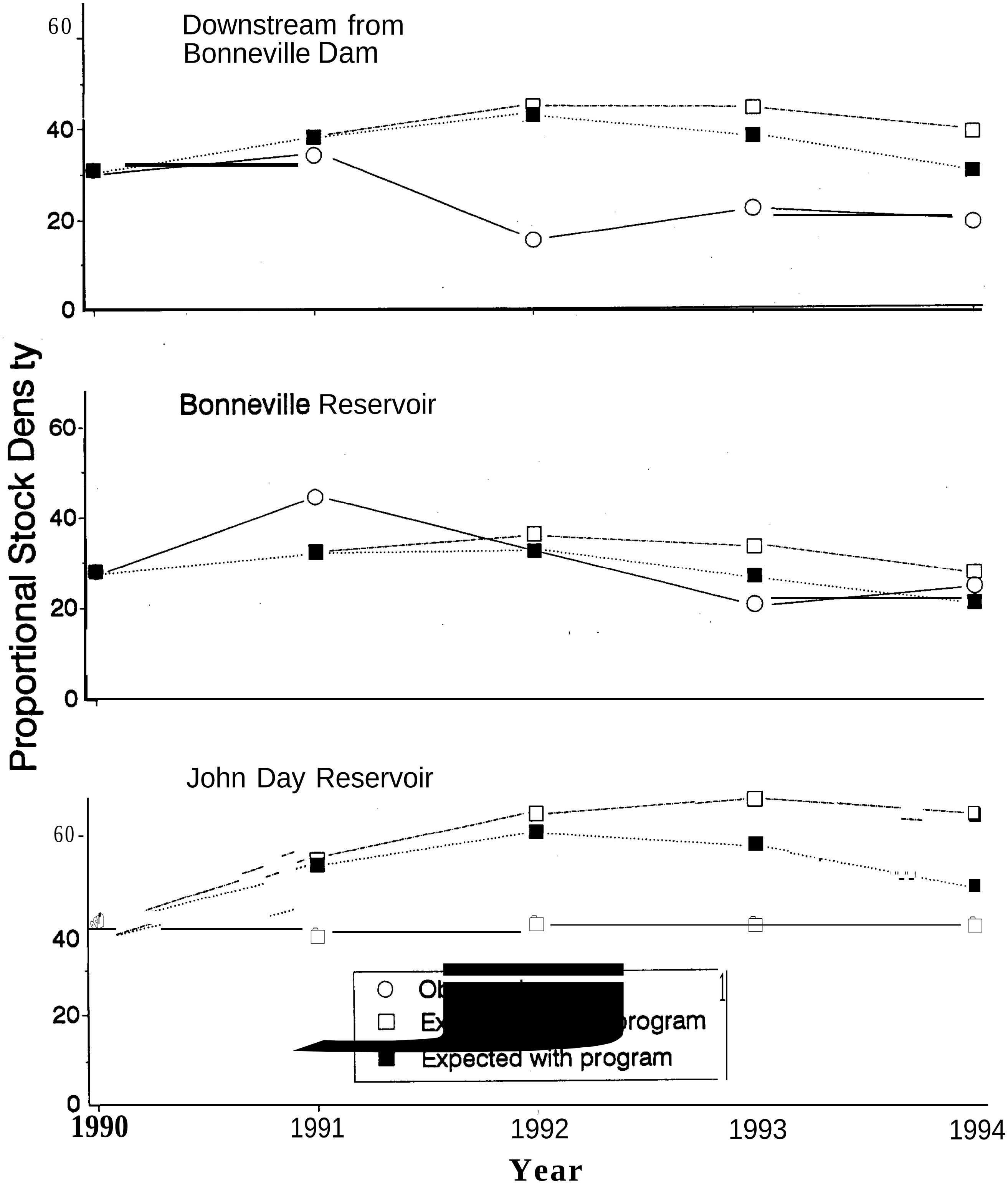

Figure 5. Observed and expected proportional stock density with and without implementation of the Northern Squawfish Management Program from 1990 through 1994 in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir.

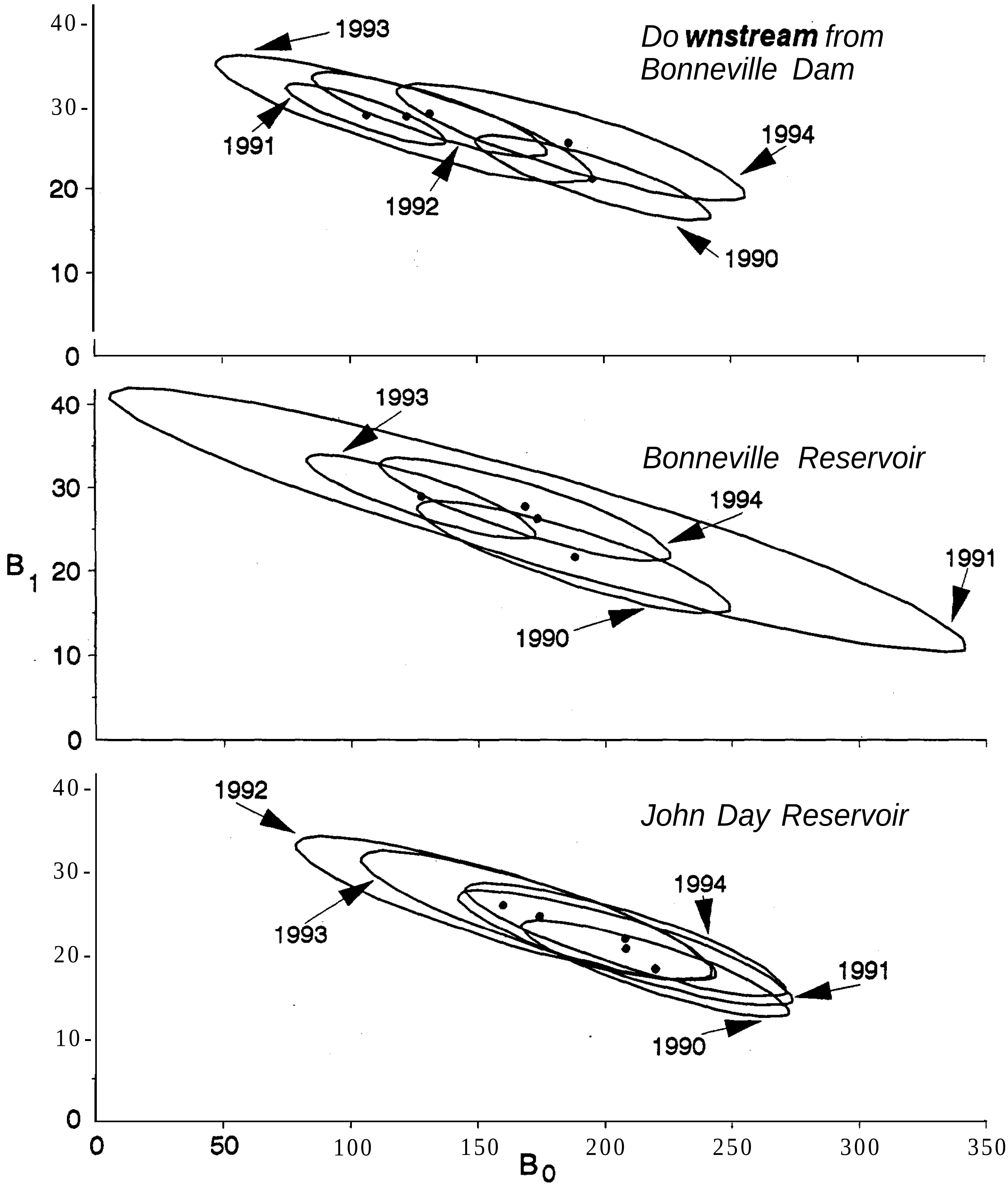

Figure 6. Joint 90% family confidence regions for estimates of length-age equation parameters (B, = slope and B_0 = y-intercept) for female northern squawfish in John Day Reservoir, Bonneville Reservoir, and the Columbia River downstream from Bonneville Dam for 1990 through 1994. No data were available for Bonneville Reservoir in 1992. Parameter pairs are considered significantly different if point estimates (solid circles) are not within the confidence region for another year.

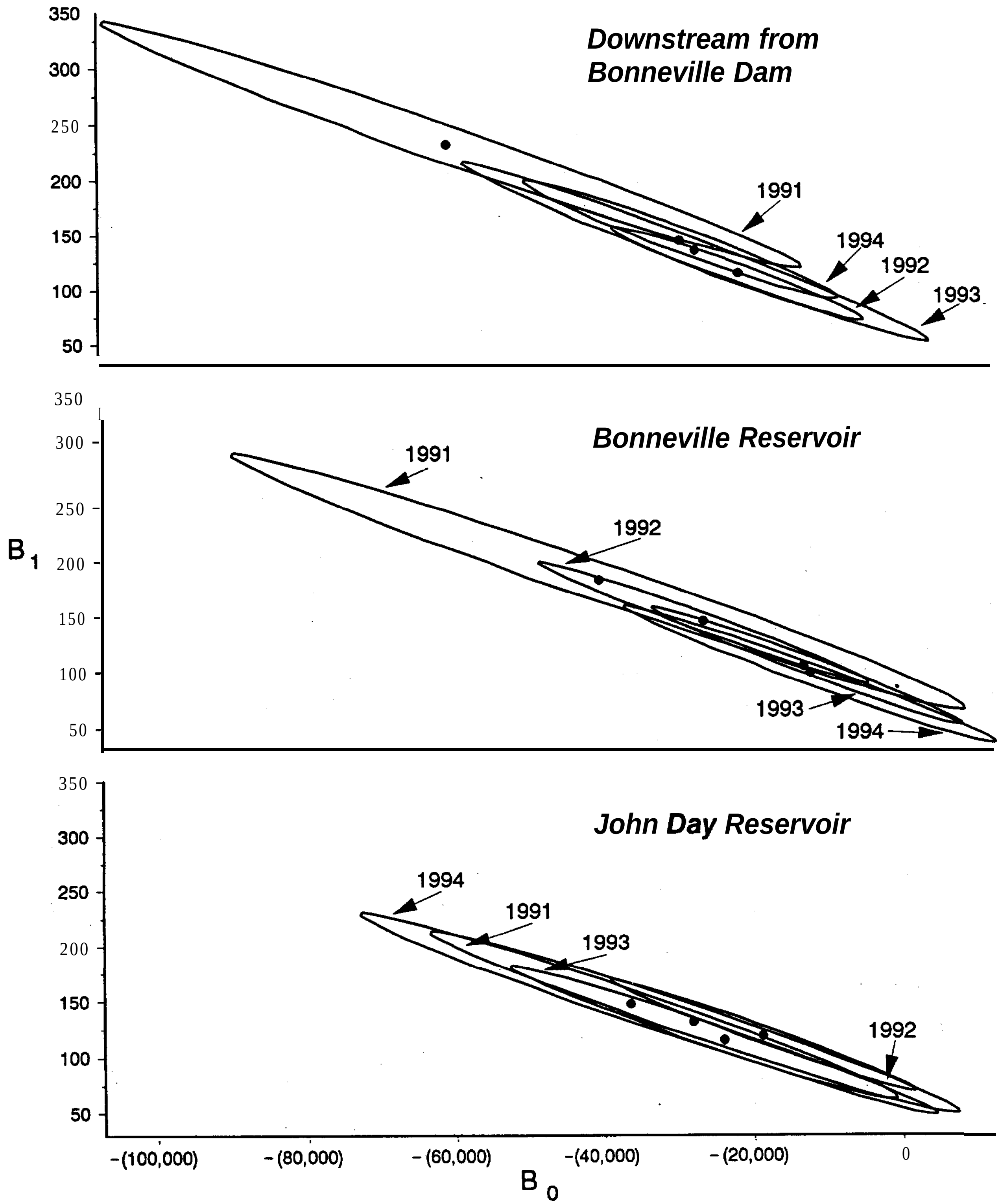

Figure 7. Joint 90% family confidence regions for estimates of fecundity-length equation parameters (B_1 = slope and B_0 = y-intercept) for northern squawfish in John Day Reservoir, Bonneville Reservoir, and the Columbia River downstream from Bonneville Dam for 199 1 through 1994. Parameter pairs are considered significantly different if point estimates (solid circles) are not within the confidence region for another year.

Table 5. Mean fecundity (number of developed eggs per female), mean relative fecundity (number of developed eggs per gram of body weight), and sample size (N) for northern squaw-fish in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir from 199 1 through 1994.

Location, parameter	1991	1992	1993	1994
Downstream from Bonneville Dam				
Mean fecundity	34,806	23,437	24,288	27,812
Mean relative fecundity	36.58	30.59	34.41	36.47
N	52	77	33	75
Bonneville Reservoir				
Mean fecundity	35,796	33,338	30,405	28,688
Mean relative fecundity	43.52	34.94	31.86	31.91
N	45	110	103	101
John Day Reservoir				
Mean fecundity	30,619	3 1,504	26,088	27,638
Mean relative fecundity	28.11	31.62	24.83	24.93
N	81	119	96	60

DISCUSSION

Systemwide exploitation was higher in 1994 than in previous years, and well within the 10-20% target range. As in the past, the sport-reward fishery contributed the most to systemwide exploitation rates. Decreases in dam angling exploitation from 1991 through 1994 may be partially attributed to apparent declines in abundance of northern squawfish in tailrace BRZs. Additionally, high spring flows, cooler water temperatures, and associated spill at dams on the Columbia and Snake rivers may have decreased the relative effectiveness of the dam angling fishery over the past two years. Exploitation by dam-angling in The Dalles Reservoir was underestimated, probably because of incomplete mixing of tagged fish. However, systemwide mixing of fish tagged within and outside of BRZs is probably close to 100% (Zimmerman et al. 1995). The site-specific gill-net fishery appears to be a viable option for harvesting known concentrations of northern squawfish. However, further removal efforts should continue to explore alternatives to help reduce numbers of incidentally caught salmonids.

Reductions in potential predation on stocks of outmigrating Snake River salmonids may reach 32% in 1995 and could reach 40% in the next five years if exploitation remains at past levels. The benefit of reduced predation to Snake River stocks may be particularly important over the next several years given record low escapement of adults in 1994. To reduce potential predation even further, every effort should be made to increase exploitation of northern squawfish. Increased promotional activities and incentives for participation in the sport-reward fishery, trolling.or casting lures from boats in restricted zones near dams as conducted by ODFW in 1994 (Appendix E), and expansion of the site-specific gill-net fishery could help enhance harvest in 1995.

Decreases in predation indices in reservoirs above Bonneville Dam were a result of lower abundance and consumption indices in those areas. Estimates of abundance may be affected by changing environmental conditions that influence vulnerability of ‘northern squawfish to our sampling gear. However, incremental decreases in abundance indices each year in areas such as Bonneville and John Day reservoirs indicate that sustained removals may be affecting abundance. Furthermore, decreases in abundance indices for Bonneville and John Day reservoirs have corresponded to decreases in population estimates based on mark and recapture (Oregon Department of Fish and Wildlife, unpublished data). We are comfortable comparing consumption indices among years because (1) timing of sampling for nor-them squawfish digestive tracts usually coincided with peaks in smolt outmigration, (2) most actively feeding northern squawfish captured during peak smolt abundance were probably feeding at the upper end of the functional relationship between consumption rate and quantity of available prey, and (3) changes in consumption indices among years were not always directly related to changes in smolt abundance.

Decreases in proportional stock density were greater than could be explained by fluctuations in year-class strength, and indicate that sustained removals may be altering the size structure of predator-sized northern squawfish. Proportional stock densities will probably continue to decrease in 1995 and 1996 as a result of relatively strong recruitment years in 1989 and 1990, increasing the number of stock-sized fish. Observed PSDs did not always parallel expected values, but continued sampling will provide a more accurate picture of year-class strength, which should increase precision of expected PSD estimates.

We were unable to detect evidence of compensation among not-them squawfish to sustained removals, either in growth or fecundity. The magnitude of variation in growth and fecundity estimates observed from 1991 through 1994 indicates the difficulty in detecting a compensatory response of northern squawfish populations to sustained removals.

Our sampling approach in 1994 appeared adequate for collecting enough northern squawfish digestive tract samples to compare consumption indices among years. We believe that sampling through 1996 should provide sufficient information on changes in northern squawfish population characteristics, and the benefit of time-series analyses will allow us to better quantify annual variation among all population parameters.

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APPENDIX A

Exploitation of Northern Squawfish by Reservoir and Fishery: 1991 through 1994

Appendix Table A-1. Exploitation rates (%) of northern squawfish ≥250 mm among fisheries in 1994. The site-specific Merwin trap fishery is excluded because only six northern squawfish ≥250 mm fork length were caught.

Area or Reservoir	Sport Reward	Dam Angling	Site-specific Gillnet	Total
Downstream from Bonneville Dam	13.7	0.1	--	13.8
Bonneville	2.2	3.7	5.3	11.2
The Dalles	9.8	0.0[a]	0.9,	10.7
John Day	3.2	2.6	0.0[a]	5.8
McNary	14:o	0.0[a]	0.0[a]	14.0
Ice Harbor	--	--	--	--
Lower Monumental	0.8	0.0[a]	0.0[a]	0.8
Little Goose	6.1	3.1	0.0[a]	9.2
Lower Granite	8.7	0.0[a]	0.0[a]	8.7
System-Wide	10.9	1.1	1.1	13.1

[a] Northern squawfish harvested, but no tags recovered.

Appendix Table A-2. Exploitation rates (%) of northern squawfish ≥250 mm for the sport-reward fishery from 1991 through 1994.

Area or reservoir	1991	1992	1993	1994
Downstream from Bonneville Dam	7.9	11.5	6.1	13.7
Bonneville	13.4	4.1	2.1	2.2
The Dalles	6.1	6.3	7.0	9.8
John Day	4.3	3.5	2.4	3.2
McNary	3.3	5.6	16.0	14.0
Ice Harbor	3.9	--	--	--
Lower Monumental	10.0	1.8	3.1	0.8
Little Goose	5.0	12.0	3.3	6.1
Lower Granite	16.8	14.7	12.6	8.7
System-Wide	8.3	9.4	6.8	10.9

Appendix Table A-3. Exploitation rates (%) of northern squawfish ≥250 mm for the dam-angling fishery from 1991 through 1994.

Area or reservoir	1991	1992	1993	1994
Downstream from Bonneville Dam	0.2	0.2	0.0[a]	0.1
Bonneville	1.8	1.0	[illegible]	3.7
The Dalles	4.4	10.9	8.1	0.0[a]
John Day	9:o			2.6
McNary	1.9	--	0.5	0.0[a]
Ice Harbor	13.6	--	--	--
Lower Monumental	17.0	6.0	--	0.0[a]
Little Goose	13.4	6.1	3.3	3.1
Lower Granite	--	--	0.0[a]	0.0[a]
System-Wide	3.0	2.7	1.3	1.1

[a] Northern squawfish harvested, but no tags recovered.

Appendix Table A-4. Dates for each period in 1994.

Period	Dates	Period	Dates
1	before May 1	12	July 10 - July 16
2	May 1 - May 7	13	July 17 - July 23
3	May 8 - May 14	14	July 24 - July 30
4	May 15 - May 21	15	July 31 - August 6
5	May 22 - May 28	16	August 7 - August 13
6	May 29 - June 4	17	August 14 - August 20
7	June 5 - June 11	18	August 21 - August 27
8	June 12 - June 18	19	August 28 - September 3
9	June 19 - June 25	20	September 4 - September 10
10	June 26 - July 2	21	September 11 - September 17
11	July 3 - July 9	22	September 18 - September 24

Appendix Table A-5. Exploitation of northern squawfish downstream from Bonneville Dam in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time. period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		Sport	Dam
1	402	--	--	--	--	--	
2	632	3	--		402	0.0075	
3	--	3	--		1031	0.0029	
4	--	2	--	--	1028	0.0019	--
5	--	5	--	--	1026	0.0049	--
6	--	10		--	1021	0.0098	--
7	--	10		--	1011	0.0099	
8	--	16	--	1	1001	0.0160	
9	--	8	--	--	984	0.0081	
10	--	13		--	976	0.0133	--
11	--	14	1		963	0.0145	0.0010
12	--	7		1	948	0.0074	--
13	--	8	--	1	940	0.0085	
14	--	4	--	2	931	0.0043	
15	--	1	--	1	925	0.0011	--
16	--	1		--	923	0.0011	--
17		1		1	922	0.0011	--
18		5			920	0.0054	--
19	--	2			915	0.0022	
20	--	2	--		913	0.0022	
21	--	5	--		911	0.0055	
22	--	3	--		906	0.0033	
Total	1034	123	1	7	--	0.1309	0.0010
Adjusted for tag loss						0.1366	0.0010

Appendix Table A-6. Exploitation of northern squawfish in Bonneville Reservoir in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures				M	Exploitation		
		Sport	Dam	Net	Misc.		Sport	Dam	Net
1	407	--	--	1	--	--	--	--	0.0025
2	--	--	--		1	406	--	--	0.0074
3	--	1	--	3	4	402	0.0025	--	0.0075
4	--	--	--	10		394	--	--	0.0254
5	--	1	--	2	--	384	0.0026		0.0052
6	--	2	--	1	--	381	0.0052	--	0.0026
7	--	1	1	--	1	378	0.0026	0.0026	
8	--	2	2	--	4	375	0.0053	0.0053	
9	--	--	5	--	2	367	--	0.0136	
10	--	--	3	--	1	360	--	0.0083	--
		--	1	--	1	356	--	0.0028	
: :	II	--	--	--	1	354	--	--	--
13	--	--	1	--	1	353	--	0.0028	
					2	351	--	--	
: ;	II	--	--	--	1	349		--	
16	--	1	--	--		348	0.0029	--	--
	--	--	--	--	--	347	--	--	--
: ;	--	--	--	--	--	347	--	--	
19	--				1	347	--		
..	--					346	--	--	
,,	--					346	--		
22	--					346	--	--	
Total	407	8	13	20	20	--	0.0212	0.0356	0.0505
Adjusted for tag loss							0.0221	0.0371	0.0527

Appendix Table A-7. Exploitation of northern squawfish in The Dalles Reservoir in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures				M	Exploitation		
		Sport	Dam	Net	Misc.		Sport	Dam	Net
:	124 --	-- --	-- --	-- --	-- --	124 --	—	--	--
3	--	1		--				--	
4	--	--	II	--	II	124 123	0.0081 --	-- --	--
5	--	1	--	--	--	123	0.0081	--	--
6	--	--	--	--	--	122			--
7		1		1			--	--	
8	II	--	II	--	--2	122 120	0.0082 --	-- --	0.0082 --
9	--	2	--	--	--	118	0.0169	--	--
10	--								
11	--	2	--	--	--	116 114	0.0172 0.0088	--	--
12	--	;	--	--	--	113	0.0088	--	--
13			--	--	1				
14	II	-- 1	--	--	--	111 110	0.0090 --	--	--
15	--	--	--	--	--	110	--	--	--
16	--	--			--				
17	--	--	II	II	--	110 110	--	--	--
18	--	--	--	--	--	110	--	--	--
19	--	--	--	--	--	110	--	--	--
20		--		--				--	
21	II	1	II	--	II	110 110	0.0091	--	--
22	--	--	--	--	--	109	--	--	--
Total	124	11	0	1	3	--	0.0943	0.0000	0.0082
Adjusted for tag loss							**0.0984**	**0.0000**	**0.0086**

Appendix Table A-8. Exploitation of northern squawfish in John Day Reservoir in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		Sport	Dam
1	166		--	--	--		--
2				--	166	--	--
3	--	--	--	--	166	--	--
4	--	1	--	--	166	0.0060	--
5	--				165		--
6			1		165	--	0.0061
7	--	3	--	--	164	0.0183	--
8	--	--	--	--	161		--
9	--	--	2	--	161	--	0.0124
10	--	1		4	159	0.0063	
11	--			1	154	--	
12					153		
13			1		153		0.0065
14	--	--	--	--	152	--	--
15	--	--	--	--	152		--
16	--	--	--	2	152	--	--
17	--	--	--	--	150		--
18					150	--	--
19			--	1	150		--
20	--	--	--	--	149	--	--
21	--	--	--	--	149		--
22	--	--	--	--	149		--
Total	166	**5**	**4**	**8**		**0.0306**	**0.0250**
Adjusted for tag loss						0.0319	0.0261

Appendix Table A-9. Exploitation of northern squawfish in McNary Reservoir in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		Sport	Dam
1					--	--	
2	448	3	--	--	448	0.0067	--
3	--	2					
4	--	1	II	II	445 443	0.0045 0.0023	-- --
5	--	4	--	1	442	0.0090	--
6	--	4	--	1	437	0.0092	--
7	--	2	--	--	432	0.0046	--
8	--	4	--	--	430	0.0093	--
9	--	5	--	--	426	0.0117	--
10		4		1			
11	II	3	II	--	421 416	0.0095 0.0072	-- --
12	--						
13	--	4 4	-- --	-- 1	413 408	0.0097 0.0098	-- -- .
14		1	--	--			
15	II	2	--	--	404 403	0.0025 0.0050	-- --
16	--	2	--	--	401	0.0050	--
17	--	1		1			
18	--	2	II	--	399 397	0.0025 0.0050	-- --
	--	5					
: ;	--	2	II	II	395 390	0.0127 0.0051	-- --
21	--	--	--	--	388	--	--
22	--	1	--	--	388	0.0026	--
Total	448	56	0	5	--	0.1339	0.0000
Adjusted for tag loss						0.1397	0.0000

Appendix Table A-10. Exploitation of northern squawfish in Lower Monumental Reservoir in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures Sport	Recaptures Dam	Recaptures Misc.	M	Exploitation Sport	Exploitation Dam
1	--			--	--		--
2	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--
5	130	--	--	--	--	--	--
6	--	--	--	--	130	--	--
7	--		--	--	130		
8	--		--	1	130		
9	--		--	--	129	--	
10	--	--	--	--	129	--	--
11	--	--	--	2	129	--	--
12	--		--	--	127		--
13	--		--	--	127		--
14	--		--	--	127	--	--
15	--	--	--	--	127		--
16	--	--	--	--	127	--	--
17	--	1	--	--	127	0.0079	--
18	--		--	--	126		--
19	--		--	--	126		--
20	--			--	126		--
21	--	--	--	--	126	--	--
22	--	--	--	--	126	--	--
Total	130	1	0	3	--	0.0079	0.0000
Adjusted for tag loss						0.0082	0.0000

Appendix Table A-11. Exploitation of northern squawfish in Little Goose Reservoir in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures			M	Exploitation	
		Sport	Dam	Misc.		Sport	Dam
1	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--
4		--	--	--	--		--
5	105	--	--	--	--	--	
6	--	--	1	--	105	--	0.0095
7	--	--	--	--	104		
8		5	--	--	104	0.0481	
9			1	--	99		0.0101
10			1	--	98	--	0.0102
11	--	--	--	--	97	--	--
12	--	--	--	--	97	--	
13	--	--	--	--	97		
14	--	--	--	--	97		
15			--	--	97		
16			--	--	97	--	--
17	--	--	--	--	97	--	--
18	--	--	--	--	97		--
19	--	--	--	--	97		--
20			--	--	97		--
21	--			--	97	--	--
22		1	--	--	97	0.0103	--
Total	105	6	3	0	--	0.0584	0.0298
Adjusted for tag loss						0.0609	0.0311

Appendix Table A-12. Exploitation of northern squawfish in Lower Granite Reservoir. in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures Sport	Recaptures Dam	Recaptures Misc.	M	Exploitation Sport	Exploitation Dam
1			--	--			
2		--	--	--			--
3	15	--	--	--	--		--
4	47	--	--	--	15	--	--
5	--	1	--	--	62	0.0161	--
6			--	--	61	--	
7		2	--	--	61	0.0328	
8			--	--	59		
9			--	--	59		
10	--	--	--	--	59	--	--
11	--	1	--	--	59	0.0169	--
12		1	--	--	58	0.0172	--
13			--		57		
14			--	--	57		
15			--	--	57		
16	--	--	--	--	57	--	--
17	--	--	--	--	57	--	--
18	--		--		57	--	--
19			--	--	57		--
20	--		--	--	57	--	
21	--	--	--	--	57		--
22	--	--	--	--	57	--	--
Total	62	5	0	0	--	0.0831	0.0000
Adjusted for tag loss						0.0867	0.0000

Appendix Table A-13. Exploitation of northern squawfish system-wide in 1994. T = number marked. M = number marked at large. Misc. = marked fish recaptured in other fisheries or in other areas.

Time period	T	Recaptures				M	Exploitation		
		Sport	Dam	Net	Misc.		Sport	Dam	Net
1	1547	--	--	1	--	--	--		0.0006
2	632	7	--	3	--	1546	0.0045		0.0019
3	15	11	--	3	--	2168	0.0051	--	0.0014
4	47	4	--	10	--	2169	0.0018	--	0.0046
5	235	13	--	2	--	2202	0.0059		0.0009
6	--	17	2	1	--	2422	0.0070	0.0008	0.0004
7	--	20	1	2	--	2402	0.0083	0.0004	0.0008
8	--	28	2	--	7	2379	0.0118	0.0008	--
9	--	17	8	--	--	2342	0.0073	0.0034	--
10	--	21		--	4	2317	0.0091	0.0022	--
11	--	22	5		1	2287	0.0096	0.0009	--
12	--	14	--	--	3	2262	0.0062	--	--
13	--	14	2	--	1	2245	0.0062	0.0009	--
14	--	6	--	--	3	2228	0.0027	--	--
15	--	4	--	--	1	2219	0.0018		--
16	--	5	--	--	1	2214	0.0023	--	--
17	--	3	1	--	1	2208	0.0014	0.0005	--
18	--	7	--	--	--	2203	0.0032	--	--
19	--	8	1	--	--	2196	0.0036	0.0005	--
20	--	4	--	--	--	2187	0.0018	--	--
21	--	6	--			2183	0.0027		--
22	--	5	--			2177	0.0023		--
Total	2476	236	24	22	22	--	0.1046	0.0103	0.0107
Adjusted for tag loss							0.1092	0.0107	0.0112

APPENDIX B

Calculations of Northern Squawfish Year-Class Strengths, Size Selectivity, and Adjustment of PSD Estimates

Year-Class Strengths

To adjust expected proportional stock density (PSD) estimates for fluctuations in northern squawfish year-class strength, we modified the method of El-Zarka (1959) to index relative year-class strengths of northern squawfish cohorts produced between 1985 and 1990 in Bonneville Dam tailrace, Bonneville Reservoir, and John Day Reservoir. The El-Zarka (1959) procedure compared the relative abundance of each year class in catches from standardized sampling over a number of years However, the relative abundance of year classes in our catches were biased by exploitation rates that varied both among years and among ages within years. We therefore limited our comparisons to the relative abundance of northern squawfish large enough to be effectively sampled by our standardized electrofishing (ages 3 and older), but small enough to be excluded from the Northern Squawfish Management Program (ages 5 and younger). Limiting our comparisons to fish 3-5 years old also eliminated potential uncertainty caused by differences between sexes in growth after age 5 (Parker et al. 1995). Analysis indicated that cyclical variation in year-class strength of northern squawfish occurred in Bonneville Dam tailrace, Bonneville Reservoir, and John Day Reservoir between 1985 and 1990 (Appendix Figure B-l).

Size Selectivity

To adjust observed PSD estimates for size-selectivity of sampling gear, we compared the recapture rate among 50-mm size groups of marked northern squawfish. For each size group, we summed the number of fish marked for 1992 through 1994 evaluations of exploitation (Parker et al. 1992, Zimmerman et al. 1995), and the number of fish marked in John Day Reservoir from April through June, 1983-86 (ODFW, unpublished data). We then summed the number of marked fish recaptured during 1992-94 standardized electrofishing, and by electrofishing in John Day Reservoir from July through August, 1983-86. Only fish marked and recaptured in the same year were included. We pooled results to determine the overall recapture rate for each size group, and used regression analysis to determine the relationship between size (fork length) and recapture rate. Analysis indicated that vulnerability of northern squawfish to standardized electrofishing increased ($r^2 = 0.90$; $P < 0.05$) with increasing fork length (Appendix Figure B-2).’

Adjustment of PSD Estimates

We used age composition of our catches rather than size composition to incorporate year-class strength information and allow comparisons between observed and expected PSDs. We used pooled 1990-93 age-at-length data to (1) back-calculate age-specific lengths for female and male northern squawfish, (2) estimate sex-specific age composition within 25-mm length intervals, and (3) estimate for each sex the proportion of each age (5 years) that were at least stock and quality size.

To estimate 1990-94 observed PSDs, we summarized sex-specific catch data into 25-mm length intervals to determine sex-specific age distributions. Sex-specific age distributions were corrected for size selectivity by dividing the observed frequency of each age by the recapture rate of the mean fork length of that age. The number of stock and quality size fish for each sex was estimated from the age distributions; observed PSDs were estimated by summing the total number of stock and quality size fish each year.

We calculated expected PSDs (with and without observed exploitation rates) for 1991-94, years subsequent to program implementation. Recruitment to age 5 varied as a function of relative year-class strength:

$$N_{5,i} = N_{5,0} \quad ((100 + Y_i) / (100 + Y_0))$$

where

$N_{5,i}$ = number of age 5 fish in year I,

$N_{5,0}$ = number of age 5 fish in 1990,

Y_i = relative year-class strength (percent deviation from mean) in year I, and

Y_0 = relative year-class strength (percent deviation from mean) in 1990.

Age composition varied as a function of natural survival rates and exploitation rates:

$$Ni,j= N_{i-1,j-1} \quad S(1 - E_{i-1,j-1})$$

where

$N_{i,j}$ = number of fish in year I of age j,

$N_{i-1,j-1}$ = number of fish in year I-l of age j-l,

S_{j-1} = natural annual survival fate

$E_{i-1,j-1}$ = exploitation rate in year I-l on fish of age j-l.

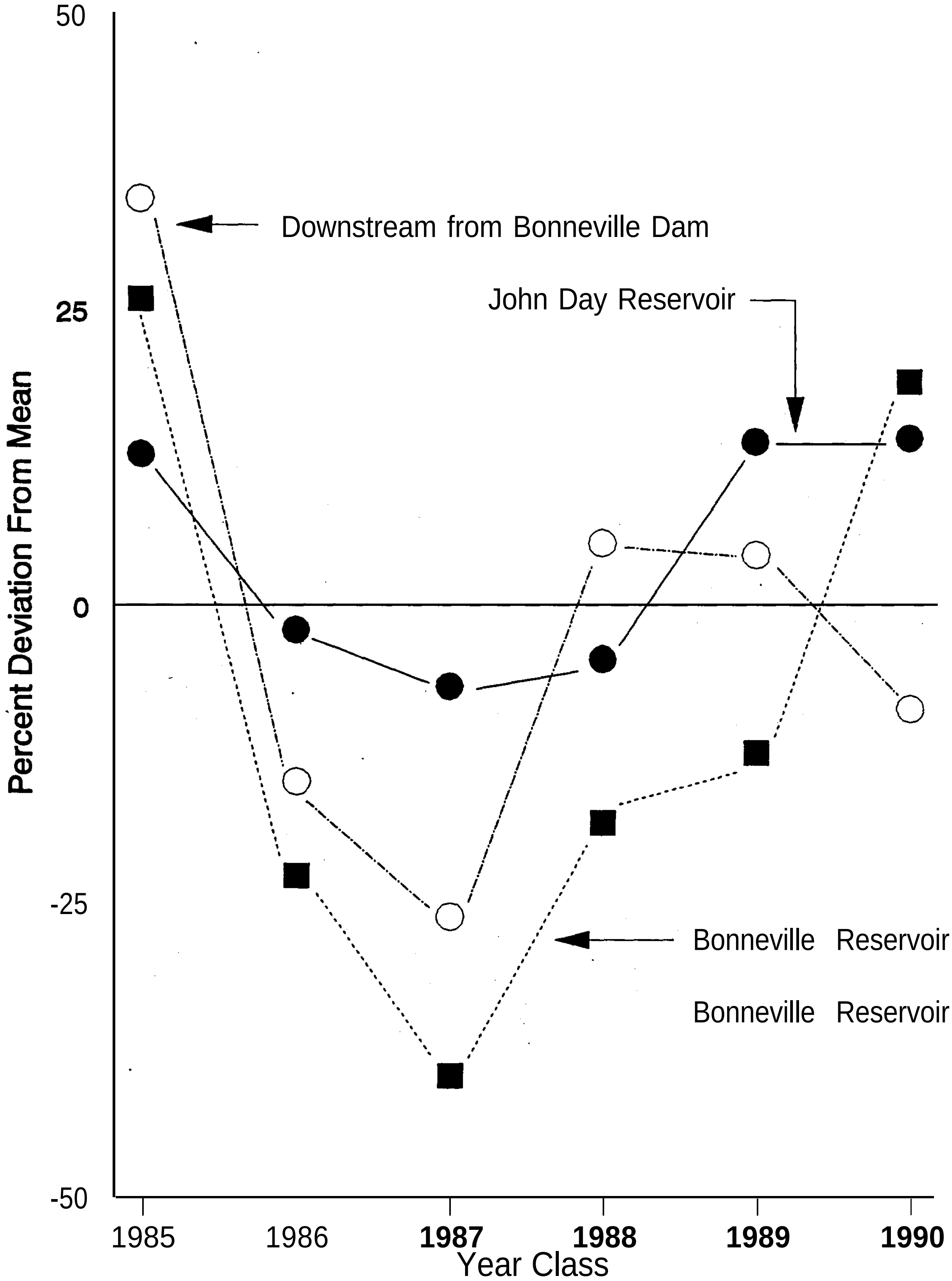
We used catch curves from 1990 data adjusted for size selectivity to estimate natural survival rates. Age distributions of the 1990 catch were estimated for each sex then combined into one catch curve. The expected number of stock and quality size fish for each sex was estimated from expected age distributions (corrected for size selectivity), and observed PSDs were estimated by summing the total number of expected stock and quality size fish each year.

References

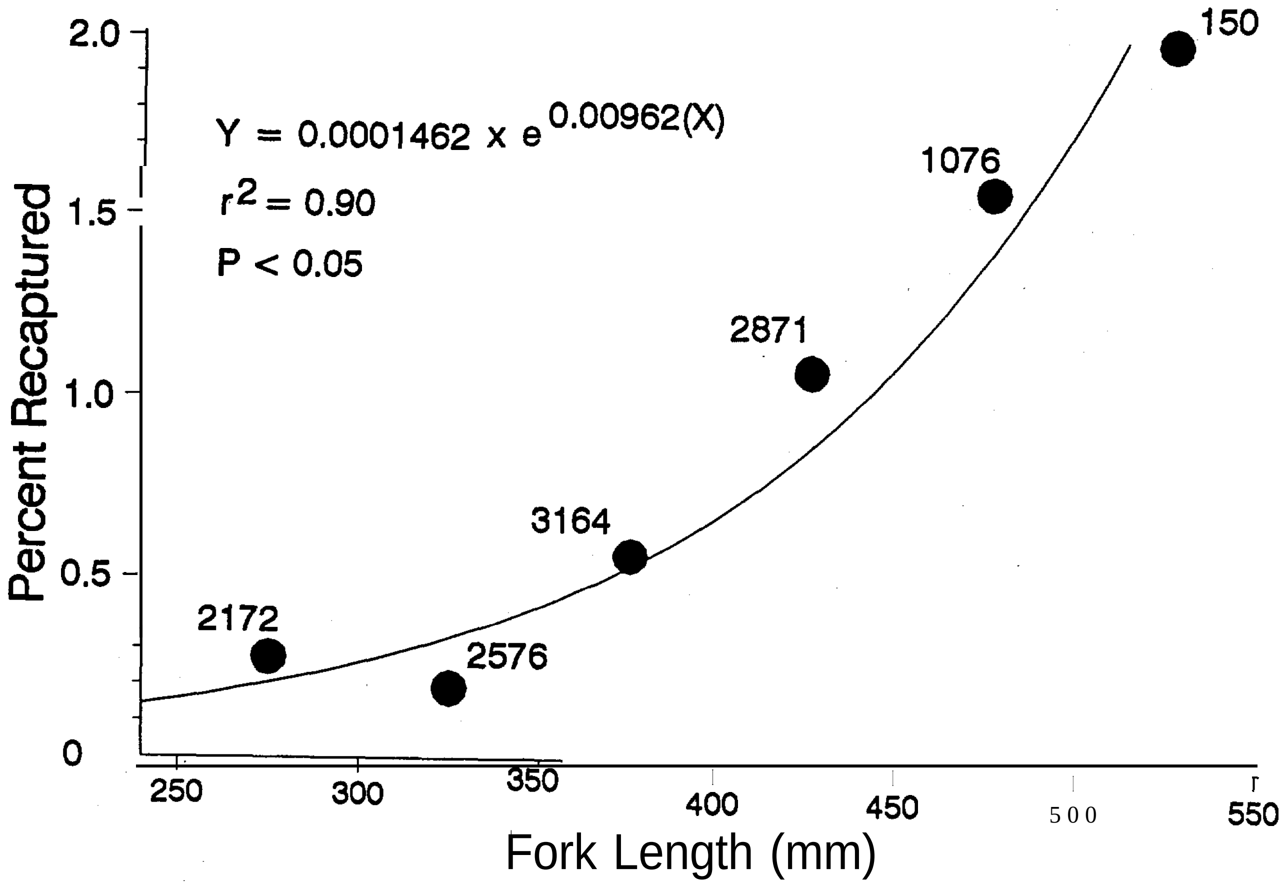
El Zarka, S.E. 1959. Fluctuations in the population of yellow perch, Perca flacescens (Mitchell), in Saginaw Bay Lake Huron. U.S. Fish and Wildlife Service Fishery Bulletin 15 1:365-415.

Parker, R.M., M.P. Zimmerman, and D.L. Ward. 1992. Development of a system-wide predator control program: indexing and fisheries evaluation. Oregon Department of Fish and Wildlife, Contract DE-AI79-90BP07096. 1992 Annual Report to Bonneville Power Administration, Portland, Oregon.

Parker, R.M., M.P. Zimmerman, and D.L. Ward. 1995. Variability in biological characteristics of northern squawfish in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society 124:335-346.



Appendix Figure B-l. Index of relative year-class strength of northern squawfish in the Columbia River downstream from Bonneville Dam, Bonneville Reservoir, and John Day Reservoir.



Appendix Figure B-2. Recapture rates for northern squawfish by 50-mm length intervals' from standardized electrofishing runs. Numbers of marked fish at large in each size group, are shown for each data, point.

APPENDIX C

Density, Abundance, Consumption, and Predation Indices from 1990 through 1994 for Sampling Locations in the Lower Columbia and Snake Rivers

Appendix Table C-l. Indices of northern squawfish density based upon catch per unit effort from standardized electrofishing runs from 1990 through 1994 for sampling zones within the Lower Columbia and Snake River. RKm = river kilometer. BRZ = boat restricted zone.

	Density Index				
Location, zone	1990	1991	1992	1993	1994
Below Bonneville Dam					
RKm 71-121	--	--	1.691	--	0.972
RKm 122-177	--	--	1.573	--	2.091
RKm 178-224	--		1.412	--	1.744
Tailrace	5.750	6,859	3.432	9.625	2.926
Tailrace BRZ	13.709	19.000	12.913	14.520	18.875
Bonneville Reservoir					
Forebay	5.711	--	i-	2.229	2.371
Mid-reservoir	2.102	--	--	1.179	0.690
Tailrace	0.512	--	--	1.103	0.600
Tailrace BRZ	5.465	--	--	1.500	6.750
The Dalles Reservoir					
Forebay	1.104	--	--	1.216	0.554
Tailrace	2.750	--	--	0.714	0.650
Tailrace BRZ	21.541	--	--	10.800	5.500
John Day Reservoir					
Forebay	0.715	0.656	1.252	0.634	0.692
Mid-reservoir	0.265	0.240	0.339	0.163	0.116
Tailrace	0.764	0.750	0.106	0.451	0.265
Tailrace BRZ	14.727	17.933	9.235	13.333	2.400
Lower Monumental Reservoir					
Tailrace	--	1.524	--	--	0.331
Tailrace BRZ	--	16.312	--	--	1.200
Little Goose Reservoir					
Tailrace	--	1.625	--	--	0.484
Tailrace BRZ	--	28.294	--	--	6.418
Lower Granite Reservoir					
Upper-reservoir	--	1.855	--	--	0.541

Appendix Table C-2. Indices of northern squawfish abundance from 1990 through 1994 for sampling locations in the Lower Columbia and Snake Rivers. RKm = river kilometer. BRZ = boat restricted zone.

	Abundance Index				
Location, zone	1990	1991	1992	1993	1994
Below Bonneville Dam					
RKm 71-121	--	--	26.8	--	15.4
RKm 122-177	--	--	19.7	--	26.2
RKm 178-224	--	--	17.9	--	22.1
Tailrace	4.5	5.4	2.7	7.6	2.3
Tailrace BRZ	3.0	4.1	2.8	3.1	4.1
Bonneville Reservoir					
Forebay	5.5	--	--	2.1	2.3
Mid-reservoir	15.2	--	--	8.5	5.0
Tailrace	0.4	--	--	0.8	0.5
Tailrace BRZ	0.9	--	--	0.2	1.1
The Dalles Reservoir					
Forebay	1.4	--	--	1.6	0.7
Tailrace	2.7	--	--	0.7	0.6
Tailrace BRZ	4.4	--	--	2.2	1.1
John Day Reservoir					
Forebay	1.4	1.3	2.5	1.2	1.4
Mid-reservoir	5.2	4.7	6.6	3.2	2.3
Tailrace	1.4	1.4	0.2	0.9	0.5
Tailrace BRZ	1.6	1.9	1.0	1.4	0.3
Lower Monumental Reservoir					
Tailrace	--	1.3	--	--	0.3
Tailrace BRZ	--	0.8	--	--	0.1
Little Goose Reservoir					
Tailrace	--	0.7	--	--	0.2
Tailrace BRZ	--	1.7	--	--	0.4
Lower Granite Reservoir					
Upper-reservoir	--	1.6	--	--	0.5

Appendix Table C-3. Indices of northern squawfish consumption of juvenile salmonids from 1990 through 1994 during spring in the Lower Columbia and Snake Rivers. RKm = river kilometer. BRZ = boat restricted zone.

	Consumption Index				
Location, zone	1990	1991	1992	1993	1994
Below Bonneville Dam					
RKm 71-121	--	--	0.5	--	0.5
RKm 122-177	--	--	1.0		
RKm 178-224	--	--	1.1	==	:::
Tailrace					3.2
Tailrace BRZ	:::	--	--	0.8	0.6
Bonneville Reservoir					
Forebay	0.6	--	--	0.7	0.2
Mid-reservoir	0.0	--	--	0.0	0.2
Tailrace	0.3	--	--	0.0	0.0
Tailrace BRZ	2.3	--	--	--	--
The Dalles Reservoir					
Forebay	0.8	--	--	0.1	0.1
Tailrace		--	--	0.0	--
Tailrace BRZ	Z	--	--	0.0	--
John Day Reservoir					
Forebay	1.5	1.9	1.9	1.5	1.0
Mid-reservoir	0.0	0.5	0.0	0.0	0.0
Tailrace	1.5	0.9	0.0	2:o	0.3
Tailrace BRZ	2.5	1.5	0.9	--	0.7
Lower Monumental Reservoir					
Tailrace	--	0.6	--	--	0.7
Tailrace BRZ	--	0.7	--	--	--
Little Goose Reservoir					
Tailrace	--	0.7	--	--	1.9
Tailrace BRZ	--	1.2	--	--	1.5
Lower Granite Reservoir					
Upper-reservoir	--	0.3	--	--	0.6

Appendix Table C-4. Indices of northern squawfish consumption of juvenile salmonids from 1990 through 1994 during summer in the Lower Columbia and Snake Rivers. RKm = river kilometer. BRZ = boat restricted zone.

Location, zone	Consumption Index 1990	1991	1992	1993	1994
Below Bonneville Dam					
RKm 71-121	--		0.3		1.8
RKm 122-177	--		1.3	--	1.5
RKm 178-224	--		1.9	--	0.4
Tailrace	0.5	--	--	1.2	0.4
Tailrace BRZ	5.5	--		1.0	2.1
Bonneville Reservoir					
Forebay	1.8			0.5	0.3
Mid-reservoir	0.0	--	--	0.0	0.0
Tailrace	0.0	--	--	0.0	0.0
Tailrace BRZ	0.8	--	--	1.0	3.2
The Dalles Reservoir					
Forebay	1.0			0.0	0.0
Tailrace	0.0			0.0	0.8
Tailrace BRZ	6.4	--	--	0.5	1.2
John Day Reservoir					
Forebay	2.4	3.1	0.7	0.6	1.2
Mid-reservoir	0.9	0.0	0.0	0.6	0.6
Tailrace	2.6	0.0	0.0	0.0	0.0
Tailrace BRZ	1137	2.8	4.6	0.6	1.9

Appendix Table C-5. Indices of northern squawfish predation on juvenile salmonids in the spring (May-June) from 1990 through 1994 for sampling locations in the Lower Columbia and Snake Rivers. RKm = river kilometer. BRZ = boat restricted zone.

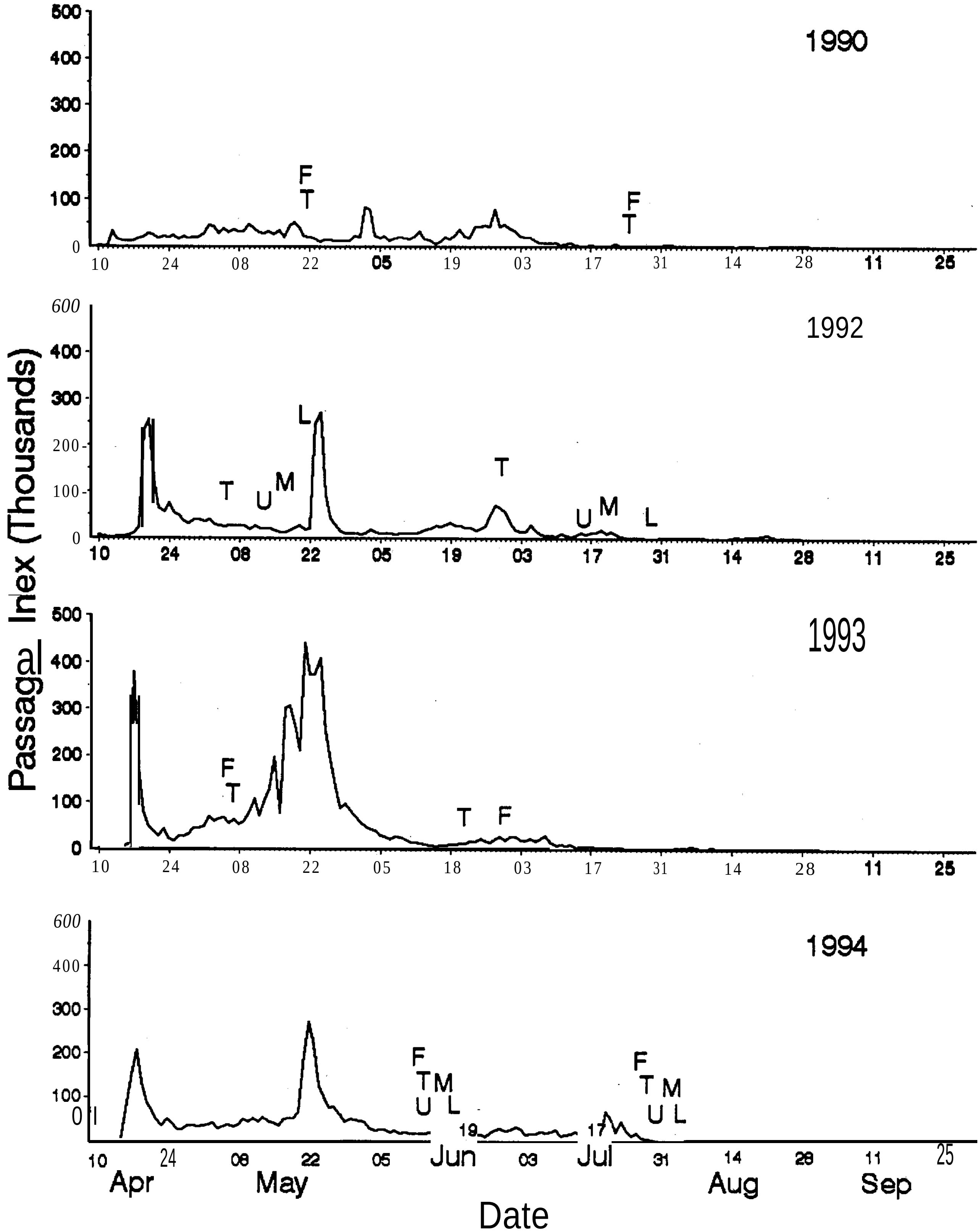
	Predation Index				
Location, zone	1990	1991	1992	1993	1994
Below Bonneville Dam					
RKm 71-121	--	--	14.0	--	8.0
RKm 122-177	--	--	20.1	--	29.7
RKm 178-224	--	--	20.2	--	33.3
Tailrace	5.5	--	--	6.1	7.4
Tailrace BRZ	8.0	--	--	3.5	2.5
Bonneville Reservoir					
Forebay	3.3	--	--	1.5	0.3
Mid-reservoir.	0.0	--	--	0.0	1.0
Tailrace	0.1	--	--	0.0	0.0
Tailrace BRZ	2.0	--	--	--	--
The Dalles Reservoir					
Forebay	1.1	--	--	0.2	0.1
Tailrace	1.9	--	--	0.0	--
Tailrace BRZ	3.9	--	--	0.0	--
John Day Reservoir					
Forebay	2.1	2.4	4.7	1.9	1.3
Mid-reservoir	0.0	2.4	0.0	0.0	0.0
Tailrace	1.9	1.3	0.0	1.7	0.2
Tailrace BRZ	3.9	2.9	0.9	--	0.2
Lower Monumental Reservoir					
Tailrace	--	0.8	--	--	0.2
Tailrace BRZ	--	0.6	--	--	--
Little Goose Reservoir					
Tailrace	--	0.5	--	--	0.4
Tailrace BRZ	--	2.0	--	--	0.6
Lower Granite Reservoir					
Upper-reservoir	--	0.5	--	--	0.3

Appendix Table C-6. Indices of northern squawfish predation on juvenile salmonids in the summer (July-September) from 1990 through 1994 for sampling locations in the lower Columbia River. RKm = river kilometer. BRZ = boat restricted zone.

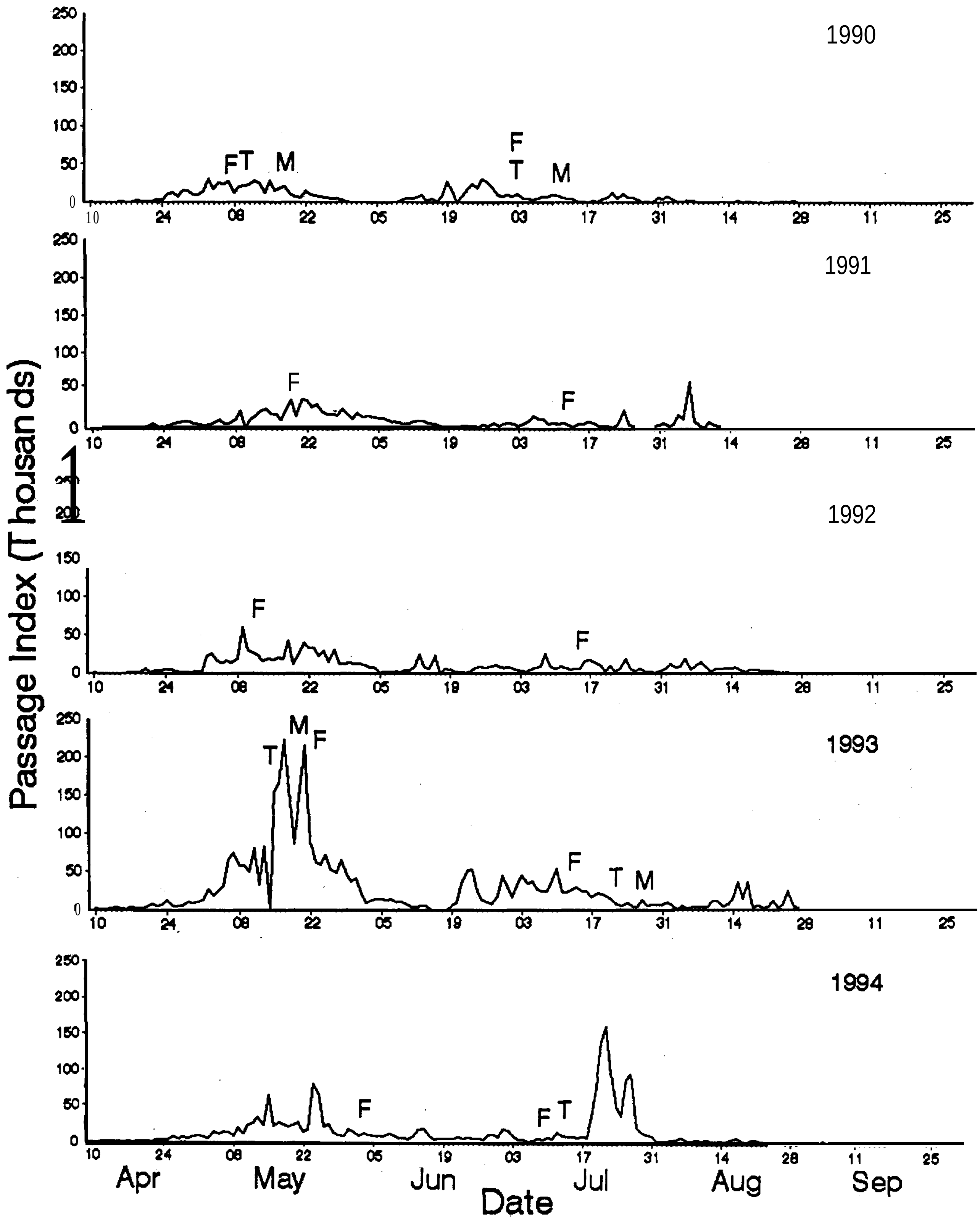
Location, zone	Predation Index 1990	1991	1992	1993	1994
Below Bonneville Dam					
RKm 71-121		--	8.3	--	27.3
RKm 122-177		--	26.1	--	39.6
RKm 178-224	--	--	33.9	--	9.5
Tailrace	2.3	--	--	9.1	1.0
Tailrace BRZ	16.4	--	--	3.2	8.9
Bonneville Reservoir					
Forebay	9.9			1.1	0.6
Mid-reservoir	0.0			0.0	0.0
Tailrace	0.0	--	--	0.0	0.0
Tailrace BRZ	0.7	--	--	0.2	3.5
The Dalles Reservoir					
Forebay	1.4			0.0	0.0
Tailrace	0.0			0.0	0.5
Tailrace BRZ	27.8	--	--	1.1	1.4
John Day Reservoir					
Forebay	3.4	4.0	1.7	0.7	1.6
Mid-reservoir	4.7	--		1.9	1.4
Tailrace	3.8	--	Y*8	0.0	0.0
Tailrace BRZ	18.6	5.4	4.6	0.9	0.5

APPENDIX D

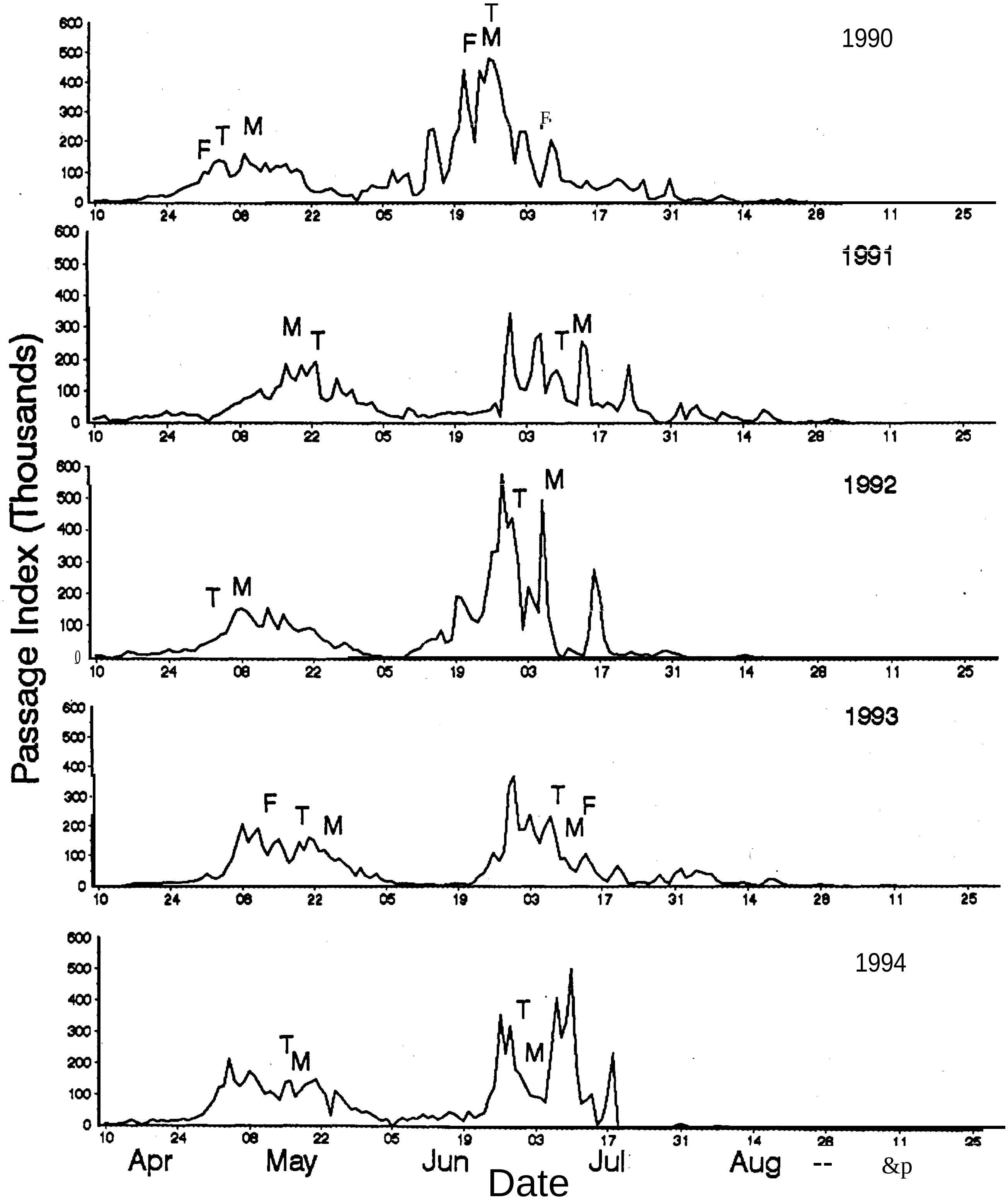
Timing of Consumption Index Sampling with Passage Indices at Lower Columbia and Snake River Dams



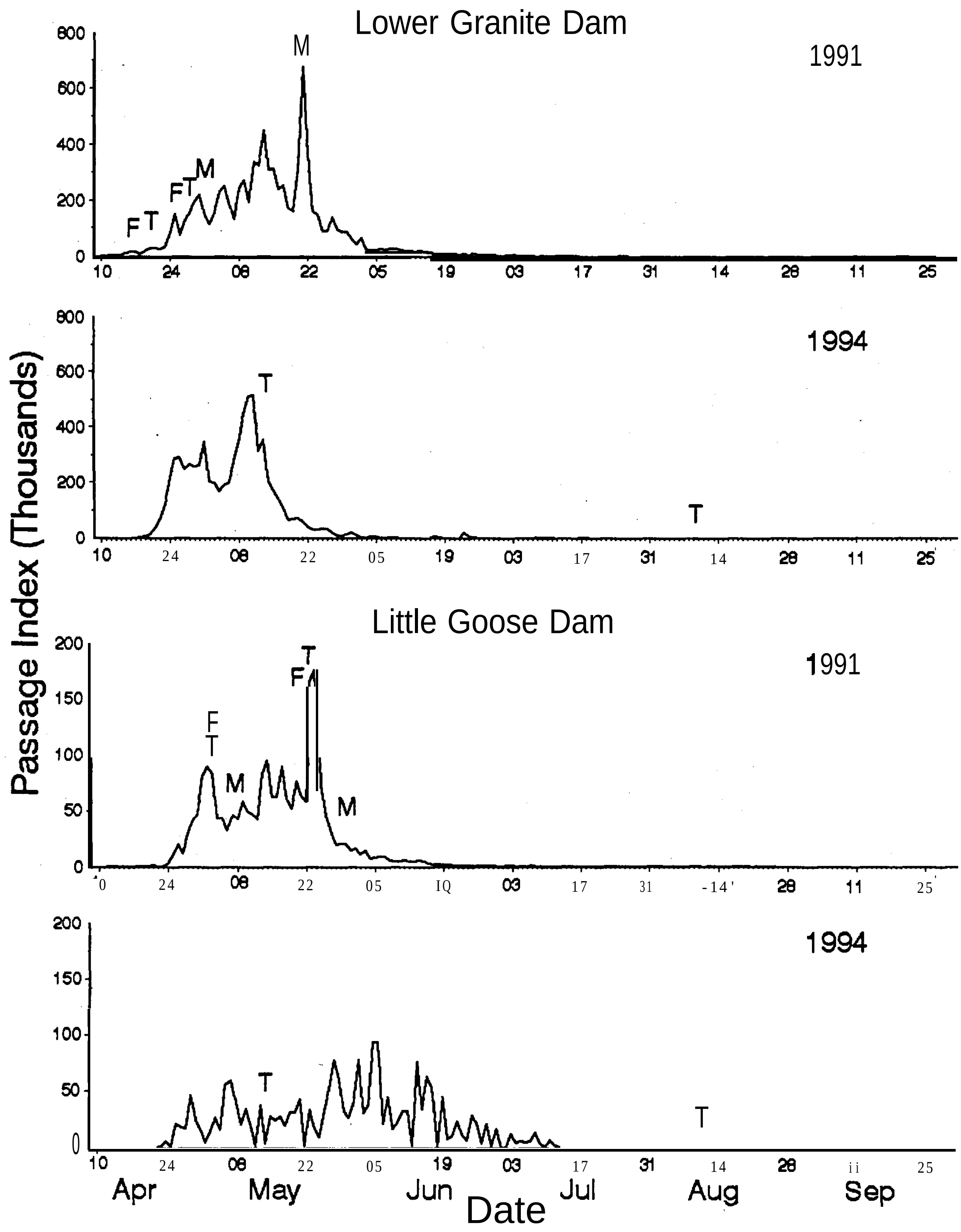
Appendix Figure D- 1. Timing of consumption index sampling with respect to juvenile **salmonid** passage indices at Bonneville Dam. Sample times for **tailrace** (T), **forebay (F),** and lower **(L),** middle **(M),** and upper **(U)** sections below Bonneville Dam are shown.



Appendix Figure D-2. Timing of consumption index sampling with respect to juvenile salmonid passage at John Day Dam. Sample times for tailrace (T), forebay (F), and the immediate downstream midreservoir (M) locations are shown.



Appendix Figure D-3. Timing of consumption index sampling with respect to juvenile salmonid passage at McNary Dam. Sample times for tailrace (T), forebay (F), and the immediate downstream midreservoir (M) locations are shown.



Appendix Figure D-4. Timing of consumption index sampling with respect to juvenile **salmonid** passage at Little Goose and Lower Granite dams. Sample times for **tailrace** (T), **forebay (F),** and the immediate downstream midreservoir **(M)** locations are shown.

APPENDIX E

Results of ODFW Lure Trolling in Bonneville Dam Tailrace Boat Restricted Zone in 1994

To further reduce predation on outmigrating juvenile salmonids in 1994, we evaluated the addition or expansion of various removal fisheries. ODFW experimented with lure trolling in 1991, and found it to be effective in limited areas of northern squawfish concentrations, such as Bonneville Dam tailrace. Over 1,100 northern squawfish were removed from this area in 1991, with a maximum catch rate of approximately 30 fish per hour (Ward et al. 1991). Incidental catch was minimal. We therefore implemented lure trolling in Bonneville Dam tailrace in 1994, designed specifically to benefit downstream migrating juvenile fall chinook salmon in June and July.

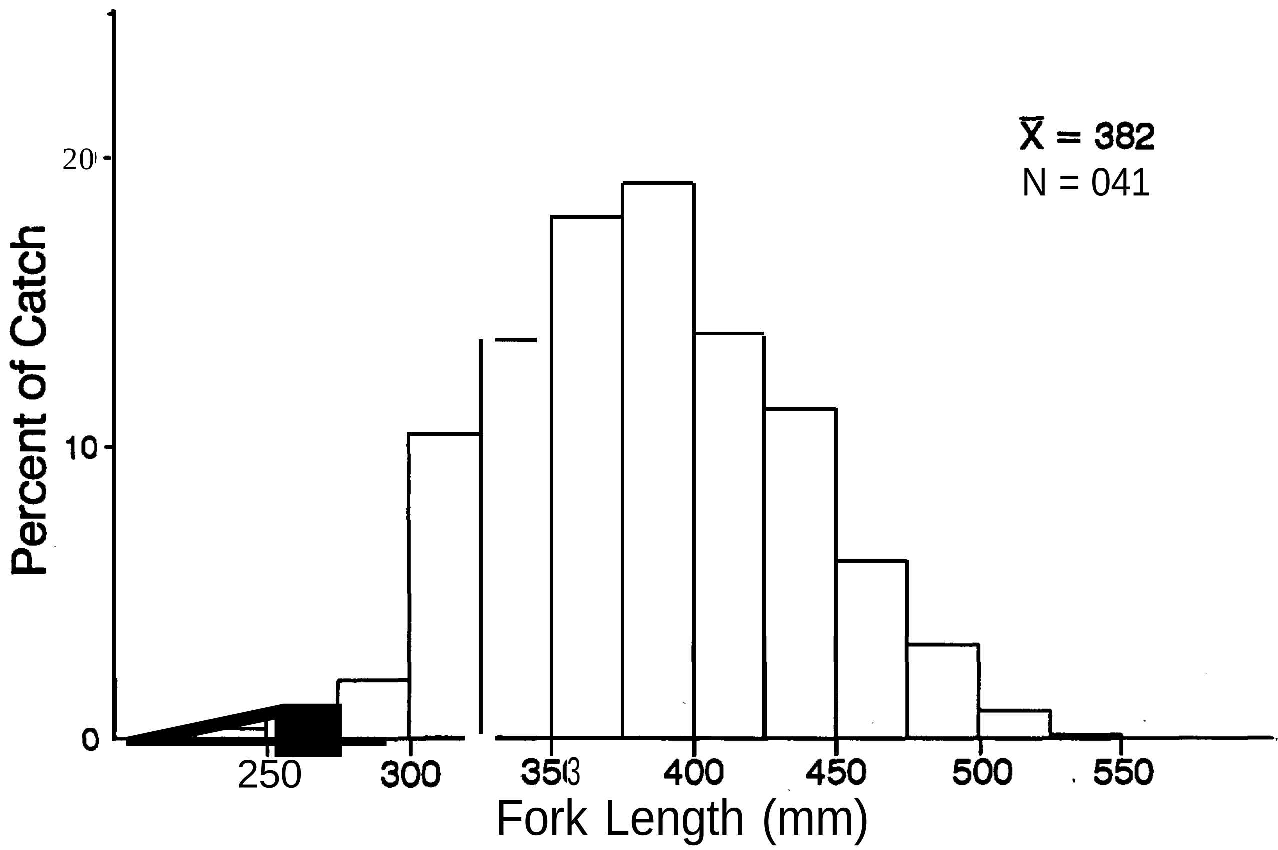
Lure trolling was conducted from June 14 to July 15 in the tailrace area of Powerhouses 1 and 2 at Bonneville Dam. Sampling gear and methods were described by Vigg et al. (1990). We measured fork length (mm) and determined sex and maturity from a subsample of northern squawfish caught.

We removed 841 northern squawfish in 76 hours for a catch rate of 11.1 fish per boat-hour. We found that casting lures from a stationary boat near juvenile bypass outfall areas was consistently more effective than trolling; casting accounted for approximately 95% of the northern squawfish catch. Fork length varied from 236 mm to 526 mm, with a mean of 382 mm (Appendix Figure E-l). No other species were captured during either trolling or casting.

References

Vigg, S., C.C. Burley, D.L. Ward, C. Mallette, S. Smith, and M. Zimmerman. 1990. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Oregon Department of Fish and Wildlife, Contract DE-BI79-90BP07084. 1990 Annual Report to Bonneville Power Administration, Portland, Oregon.

Ward D.L., M.P. Zimmerman, R.M. Parker, and S.S. Smith. 1991. Development of a system-wide predator control program: indexing, fisheries evaluation, and harvesting technology development. Oregon Department of Fish and Wildlife, Contract DE-BI79-90BPO7084. 199 1 Annual Report to Bonneville Power Administration, Portland, Oregon.



Appendix Figure E-l. Size composition and mean fork length of northern squawfish harvested while trolling and casting lures in Bonneville Dam tailrace (BRZ) in June and July, 1994.

APPENDIX F

Comparison of Digestive Tract Contents of Northern Squawfish and Smallmouth Bass Caught in the Lower Columbia and Snake Rivers in 1993 and 1994

We examined digestive tract contents of 2,077 northern squawfish and 1,365 smallmouth bass caught during standardized electrofishing in 1993 and 1994 (Appendix Tables F-l and F-2). We found salmonids in 15.2% of northern squawfish digestive tracts and 3.6% of smallmouth bass stomachs examined. Occurrence of salmonids in northern squawfish digestive tracts and smallmouth bass stomachs varied seasonally each year. Of locations for which data were collected each year, occurrence of ingested juvenile salmonids was highest for northern squawfish caught in Bonneville Dam tailrace (20.3%) and smallmouth bass caught in John Day Reservoir (4.7%).

Appendix Table F-l. Number of northern squawfish and smallmouth bass digestive tracts (N) examined from the lower Columbia River in 1993 that contained food, fish, and juvenile salmonids.

Period: Reservior or area	Northern squawfish N	Food	Fish	Salmonids	Smallmouth bass N	Food	Fish	Salmonids
Spring:								
Bonneville Dam tailrace	138	138	68	48	4	4	1	0
Bonneville	52	48	14	1	24	57	14	0
The Dalles	40	40	13	15	76	56	28	1
John Day	37	24	17		67		31	0
Summer:								
Bonneville Dam tailrace	142	139	25	15	10	9	4	1
Bonneville	163	163	28	13	53	31	17	0
			15			67		0
The Dalles / John Day	[illegible]	[illegible]	67	[illegible]	[illegible]	119	[illegible]	12

Appendix Table F-2. Number of northern squawfish and smallmouth bass digestive tracts (N) examined from the lower Columbia and Snake rivers in 1994 that contained food, fish, and juvenile salmonids. No samples were collected in Lower Granite Reservoir during the summer.

Period: Reservoir or area	Northern squawfish				Smallmouth bass			
	N	Food	Fish	Salmonids	N	Food	Fish	Salmonids
Spring:								
Below Bonneville Dam tailrace	90	51	27	18	33	28	22	2
Bonneville Dam tailrace,	152	72	33	25	7	6	4	
Bonneville	169	116	17	8	110	75	28	8
The Dalles	22	20	2	1	58	40	6	0
John Day	35	21	12	9	147	113	48	5
Lower Monumental	37	6		3	23	17	12	3
Little Goose	41	34	3:	28	8	5	3	1
Lower Granite		29	16	9	49	32	20	10
Summer:								
Below Bonneville' Dam tailrace	86	58	31	16	37	29	22	2
Bonneville Dam tailrace	80	29	21	16	14	10		0
Bonneville	204	151	18	28	117	100	40	3
The Dalles	97	61	30	13	106	76	32	0
John Day	97			24	191	146	55	9
				1	0	--	--	
Lower Monumental / Little Goose	20 / 10	19 / 15	14 / 11	9	0	--	--	II